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Monographs on Medicinal Plants along Ganga River
Ficus racemosa L.

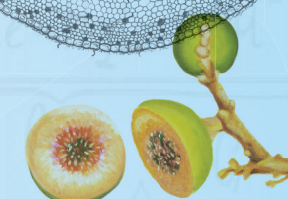
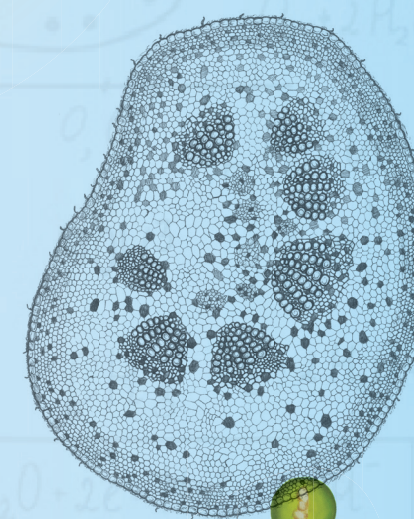


Monographs on Medicinal Plants
along Ganga River

Ficus racemosa L.

Focusing on
Botanical, Phytochemical, Scientific Validation and
Insilico Analysis Including Medicinal Importance
and Soil Properties

Volume 4



Monographs on Medicinal Plants along Ganga River

Ficus racemosa

Focusing on
Botanical, Phytochemical, Scientific validation and Insilico
analysis including Medicinal importance and Soil properties

Volume 04

Sponsored by



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Implemented by Patanjali Organic Research Institute Pvt. Ltd. (PORI)
Food & Herbal Park, Village-Padartha, Laksar Road, Haridwar-249407, Uttarakhand (India)



ABOUT THE EDITOR

Dr. Acharya Balkrishna, Co-founder of Patanjali Organic Research Institute, is a highly ascetic entrepreneur with a diverse personality who is a specialist in Yoga, Ayurveda, Sanskrit language, Indian sacred books, and the Vedas. Dr. Balkrishna has become a significant source of inspiration for Traditional Medicinal Practitioners and a globally recognized celebrity after dedicating his life to the resurrection of ancient healing and living practices. His maverick leadership as Co-Founder & Managing Director of Patanjali Ayurved Limited, along with overseeing Patanjali Food and Herbal Park and Divya Pharmacy, has propelled Ayurveda into a global business phenomenon with a massive following. Additionally, he has been decorated with prestigious awards such as 'Ayurveda Expert', 'Manav Ratan', 'Bharat Gaurav', 'Indian of the Year', 'Ten Versatile and Dynamic Young Men of India', 'Bheeshma Pusaka', 'Lokmanya Tilak', and 'Transformational Business Leader' for his exceptional knowledge, passion, and service to mankind. According to a study published by Stanford University in the USA and Elsevier in Europe, Dr. Balkrishna has been recognized among the top 2% of scientists worldwide for his research on Ayurveda and Yoga.

With his early age passion for plants, he has become the most renowned & respected herbal specialist for health and nutrition. For the research of novel herbal medication formulations, he explored four rare plants: 'Sanjeevani', 'Somlata', 'Swarnakshiri', 'Swarnadraka', and 'Astavavarga plants'. He has taken many initiatives for Biodiversity conservation, presently working for the establishment of Patanjali Herbal Garden & herbarium, working on the compilation of a unique multivoluminous project i.e., 'World Herbal Encyclopaedia', containing the descriptions of ~50,000 medicinal plant species with the largest collection of plant paintings and drawings. This is being done to strengthen traditional medicine systems of the world. Additionally, Dr. Balkrishna has made significant contributions to the socio-economic development of tribal communities and the upliftment of rural communities with FPOs, CLFs, and SHGs. Furthermore, his endeavors have been directed towards exploring and conserving floral diversity, phytochemical and insilico analysis, investigating soil geochemistry, understanding complex plant-microbe relationships, and monitoring water quality from Gomukh to Gangasagar.

He has published more than 400 research articles in national and international journals received around 20 patents and authored more than 200 books on Yoga, Ayurveda, Agriculture, Herbal Medicine,

and Information Technology and edited more than 40 unpublished ancient Ayurveda manuscripts. With the vision of ensuring universal health for the last two decades, more than 1.5 million patients with several persistent, chronic, and non-communicable diseases have been effectively treated. He established Patanjali Ayurved College and the University of Patanjali with the humanitarian goal of assisting youngsters in achieving their goals and serving the country. Additionally, he has been involved in various government and non-government initiatives. He is also a key proponent of agricultural transformation through organic practices, working to boost agricultural productivity, increase farmer income, and ensure equitable access to a safe, affordable, and nutritious diet year-round. Apart from this, Dr. Balkrishna is actively participating in driving agricultural transformation through the 'Patanjali Farmer Samridhi Programme' by well-trained staff and around one lakh trainers. His generous personality is also reflected through his actions like helping the nation with emergency needs like post-disaster needs assessment, providing free shelter, food, and education to orphan children, and free OPD services at Patanjali Yogpeeth. With his humanitarian attitude, Dr. Balkrishna continues his phenomenal journey of making world records, uplifting mankind through medicine & lifestyle improvement, reviving sustainable agriculture, and preserving nature's gifts in the form of literature and a sustainable living approach.





Vision of Honourable Prime Minister

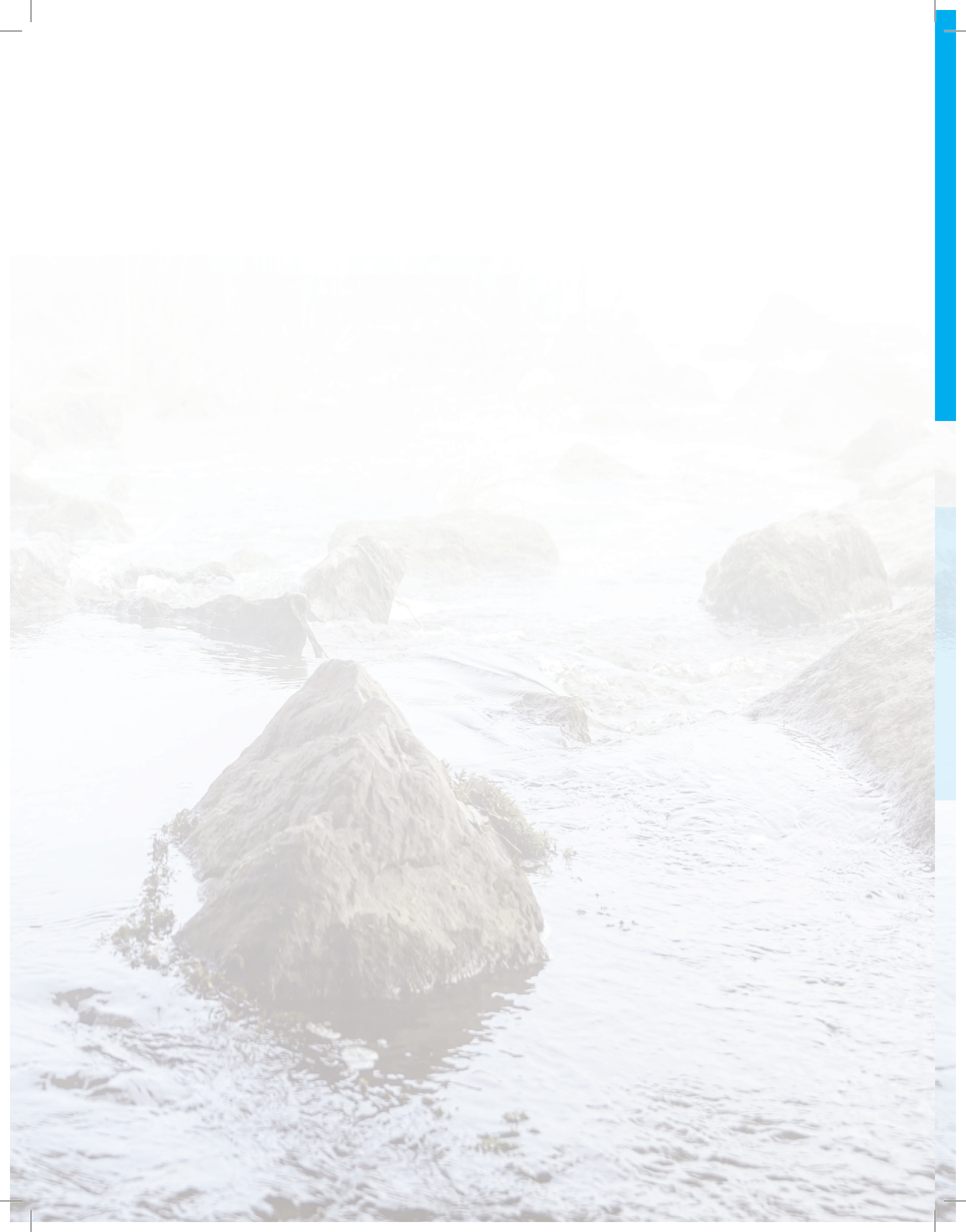
Shri Narendra Modi on Medicinal Plants



1. India's rich biodiversity of medicinal plants can provide affordable healthcare solutions.
2. Medicinal plants are nature's gift to humanity; we must protect and utilize them wisely.
3. Let us revive and promote the use of medicinal plants in everyday life.
4. India's biodiversity of medicinal plants is a treasure trove waiting to be explored.
5. Medicinal plants have been an integral part of our cultural heritage, offering natural remedies for various ailments.
6. The knowledge embedded in our traditional systems like Ayurveda and the use of medicinal plants can address global health challenges sustainably.
7. We must promote research and innovation in harnessing the potential of medicinal plants for healthcare and economic development.



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Vision of Union Minister for Jal Shakti

Shri Chandrakant Raghunath Patil

“

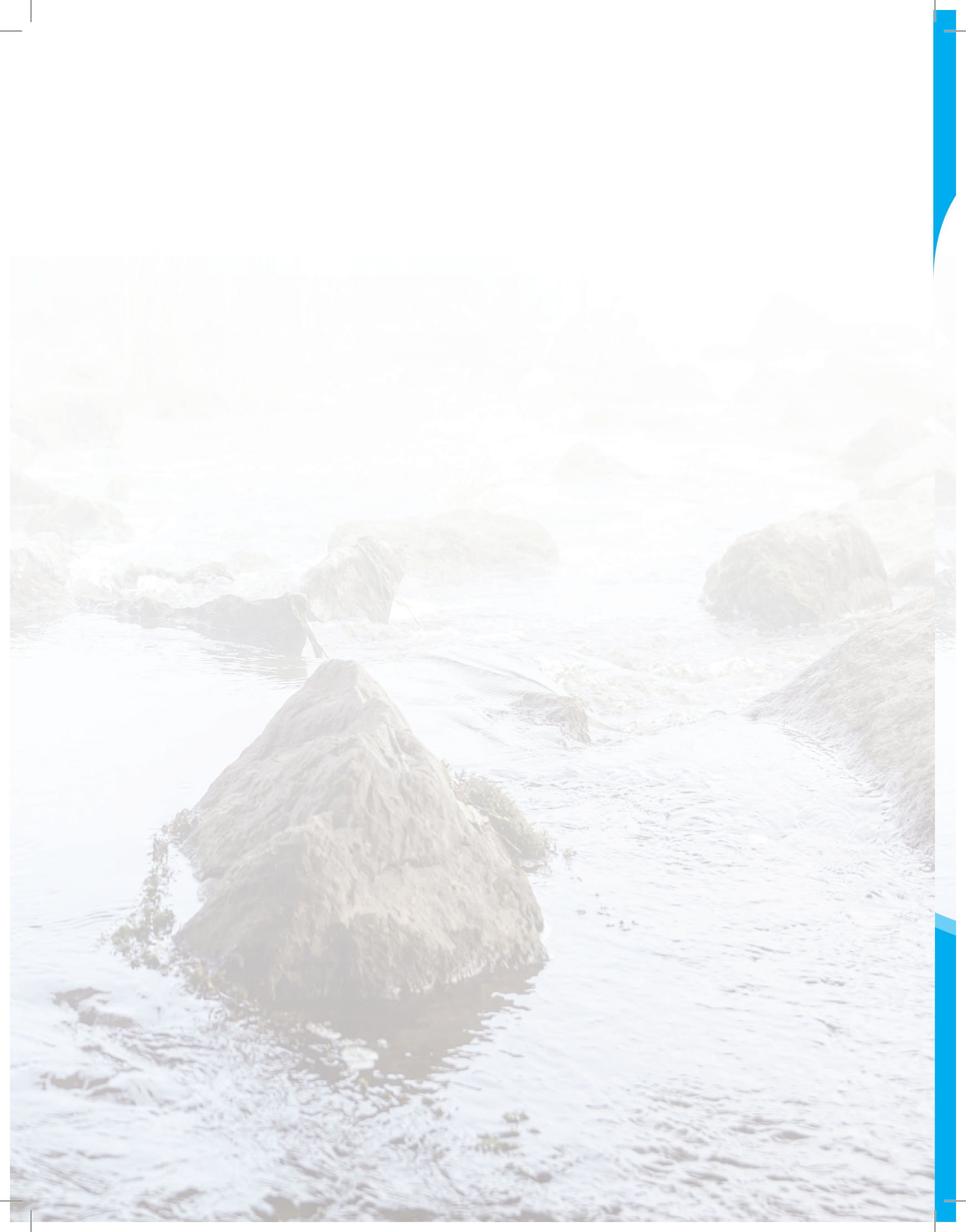
1. We will understand the importance of water, conserve it and ensure rich water resources for future generations.
2. Conservation and enhancement of water resources of our country is a sacred goal. I will work with my dedication and devotion to achieve this.
3. Proper access to water is a strong step towards women's empowerment.
4. Jal Shakti is Nari Shakti, as women are the most affected by water scarcity due to their household responsibilities in rural India.

”

<https://pib.gov.in/PressReleaseDetail.aspx?PRID=2024324>

<https://www.newsonair.gov.in/c-r-patil-emphasizes-water-access-as-essential-for-womens-empowerment-at-catch-the-rain-2024-workshop-in-delhi/>

<https://www.indiatvnews.com/gujarat/will-transform-jal-shakti-into-rashtra-shakti-cabinet-jal-shakti-minister-c-r-patil-after-portfolio-appointment-pm-modi-2024-06-10-936272>



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Ministry of Environment, Forest and Climate Change (MoEFCC)

Uttarakhand Forest Department & Biodiversity Board

Uttar Pradesh Forest Department & Biodiversity Board

Bihar Forest Department & Biodiversity Board

Jharkhand Forest Department & Biodiversity Board

West Bengal Forest Department & Biodiversity Board

Ganga Task Force (GTF)

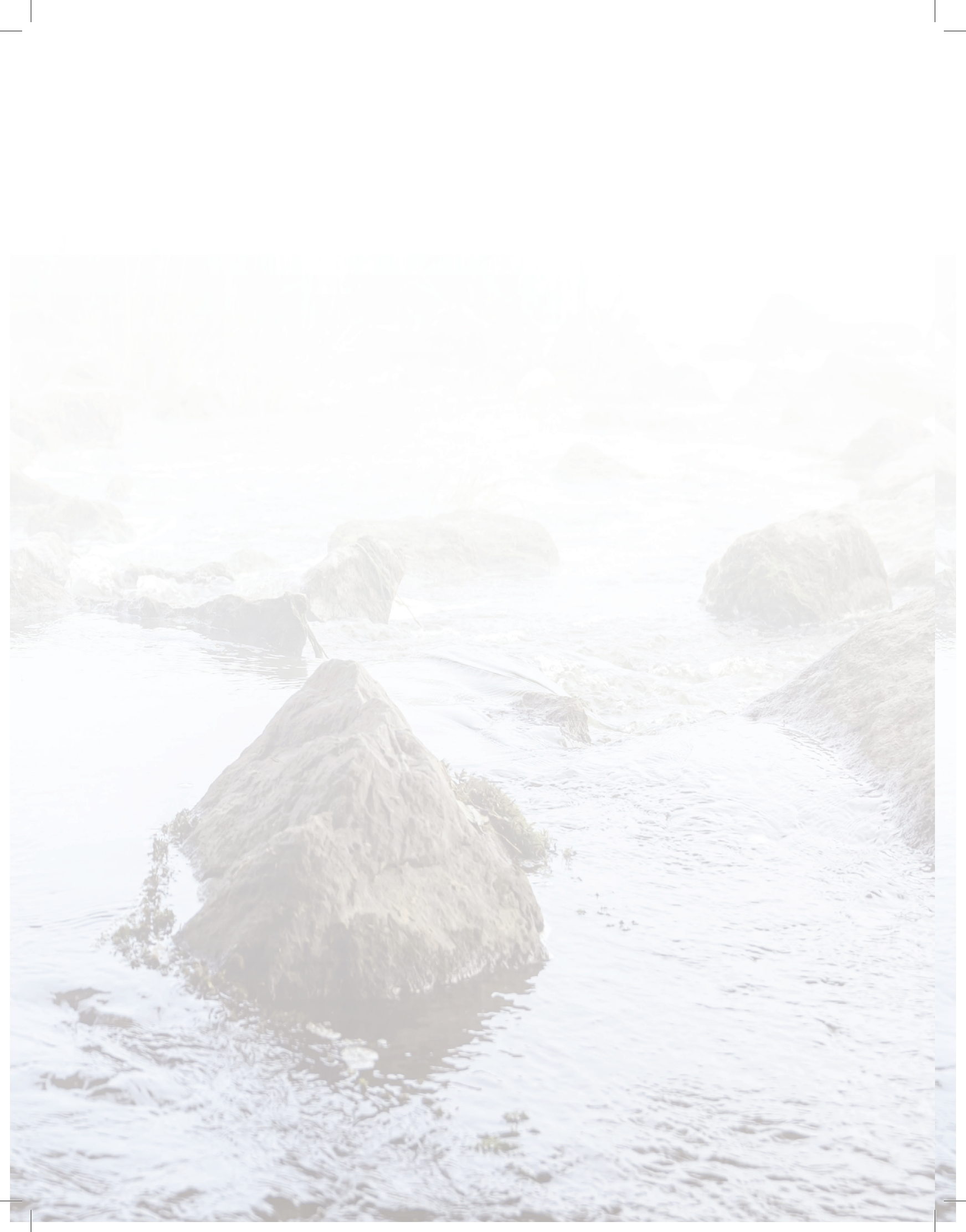


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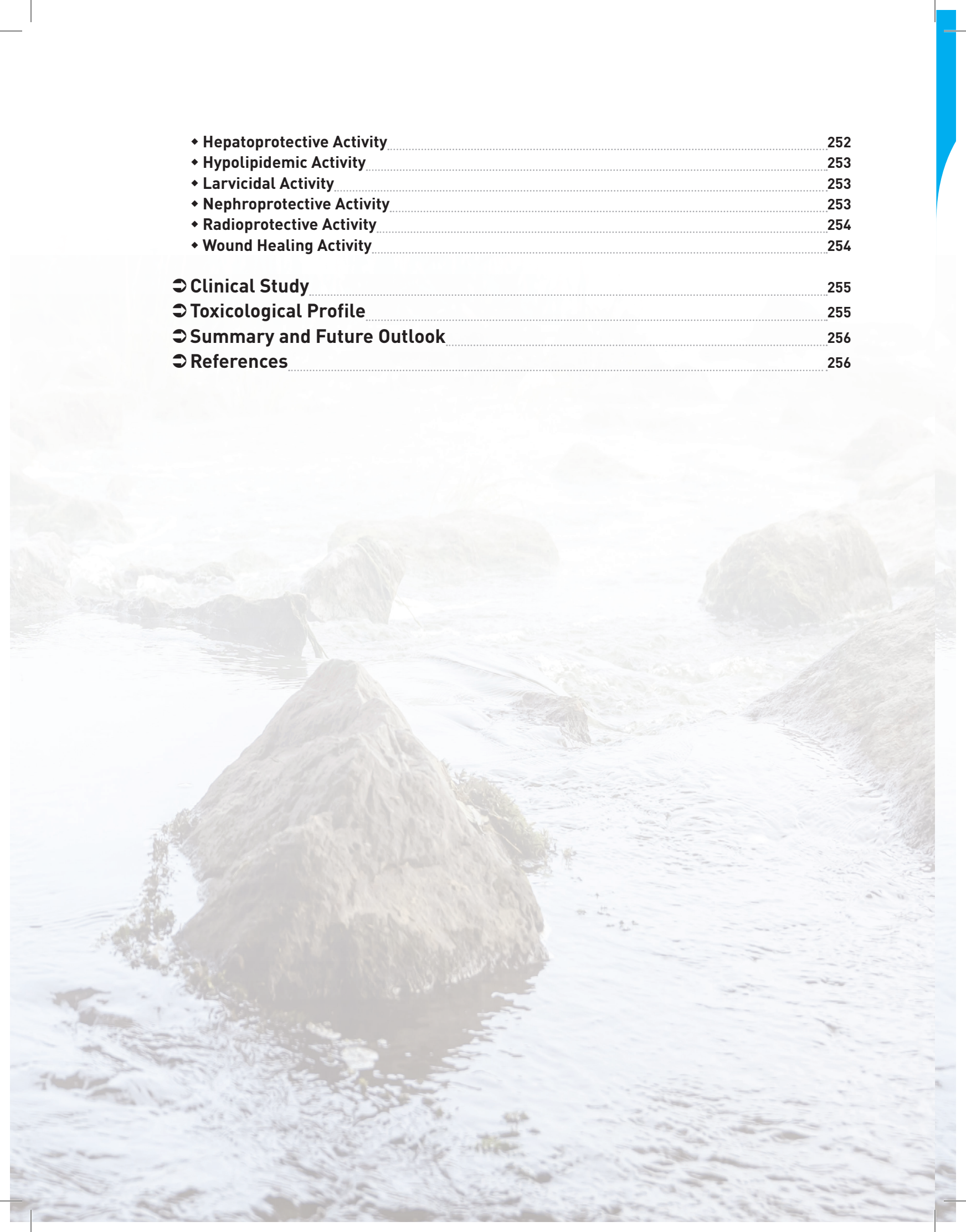
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DIRECTOR GENERAL
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सत्यमेव जयते
75
आज़ादी का
अमृत महोत्सव

भारत सरकार
जल शक्ति मंत्रालय
जल संसाधन,
नदी विकास और गंगा संरक्षण विभाग
GOVERNMENT OF INDIA
MINISTRY OF JAL SHAKTI
DEPARTMENT OF WATER RESOURCES,
RIVER DEVELOPMENT & GANGA REJUVENATION



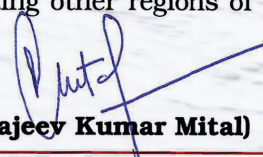
MESSAGE

The Ganga, a river deeply revered in our culture, is both a source of spiritual inspiration and home to diverse ecosystems, including riparian buffers along its banks that connect terrestrial and aquatic systems. These buffers play a crucial role in supporting amphibious life, stabilizing the riverbanks, and maintaining ecosystem services. Therefore, under the "Aviral Ganga" approach for biodiversity conservation and "Arth Ganga" for enhancing livelihoods, a project on floral diversity has been initiated through Namami Gange Mission – II, in collaboration with Patanjali Organic Research Institute (PORI), Haridwar, Uttarakhand.

The project "Scientific Exploration of Floral Diversity Near the Ganga Riverbanks for Ethnobotanical Purposes along with their Conservation and Economic Development of the Region via Skill Development Programs" aims to provide valuable scientific insights into the region's ethnobotanical wealth while promoting sustainable conservation practices. The 18-month study, conducted from Gaumukh to Gangasagar along the Ganga banks, reveals the floral profile, ethno medicinal aspects, applications, livelihood perspectives, and the role of biodiversity in ecosystem resilience, highlighting the symbiotic relationship between conservation and socio-economic development. Findings presented through publications, including project reports, monographs, exploration of ethno medicinal plants, and plant wealth along river Ganga India, will benefit stakeholders, including local communities' well-being.

It gives me immense pleasure to extend my appreciation to the entire team for successfully executing the project, which advances our understanding of the unique floral diversity along the Ganga and its role in ethnobotanical purposes, conservation, and integrating science with local knowledge. The project's focus on environmental stewardship and skill enhancement for sustainable livelihoods is commendable.

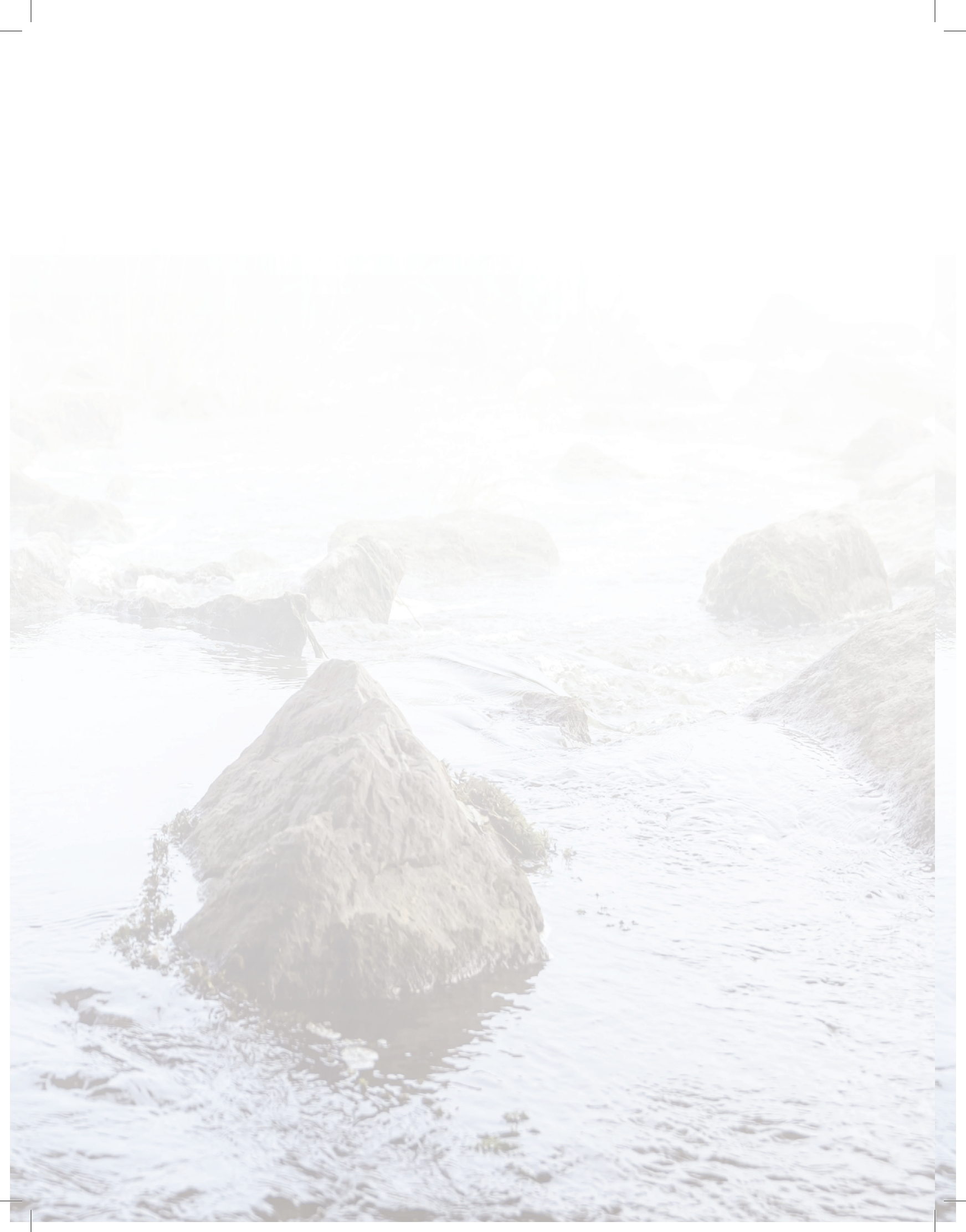
This excellent work documenting the floral diversity along the banks may pave the way for the rejuvenation of the Ganga and set a precedent for biodiversity conservation and socio-economic improvement, potentially benefiting other regions of India as well.


(Rajeev Kumar Mital)



राष्ट्रीय स्वच्छ गंगा मिशन
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FOREWORD

*I*n the timeless flow of the sacred Ganga River, lies a profound treasure trove of nature's healing bounty. As we embark on this journey through the pages of this book on Medicinal Plants along the Ganga River, we are reminded of the ancient wisdom that has sustained our civilization for millennia. The Ganga, revered not only for its spiritual significance but also for its ecological richness, nurtures a diverse array of medicinal plants. The plant, meticulously documented in this comprehensive work, are not merely botanical specimen but living reservoir of phytochemicals that hold immense therapeutic potential.

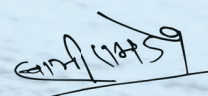
The authors have meticulously documented the plant exploration and botanical study, soil properties analysis, phytochemical analysis, and insilico analysis of the plants found in this region. Their dedication and deep respect for nature's wisdom are evident throughout the pages, making this monograph an invaluable resource for all who seek to deepen their understanding of the healing potential found in the lap of the Himalayas.

Moreover, the inclusion of phytochemical and bioinformatic aspects adds a modern scientific perspective to this ancient knowledge. By unraveling the chemical constituents and molecular mechanisms behind the therapeutic effects, this monograph bridges the gap between traditional wisdom and contemporary scientific advancements, paving the way for evidence-based herbal medicine.

I extend my heartfelt appreciation to Acharya Balkrishna Ji and his devoted team of expert scientists for their unwavering commitment for preserving and disseminating the wisdom of the Medicinal Plants along Ganga River. Their work not only contributes to the scientific community but also instills a deep reverence for nature and its intricate web of life.

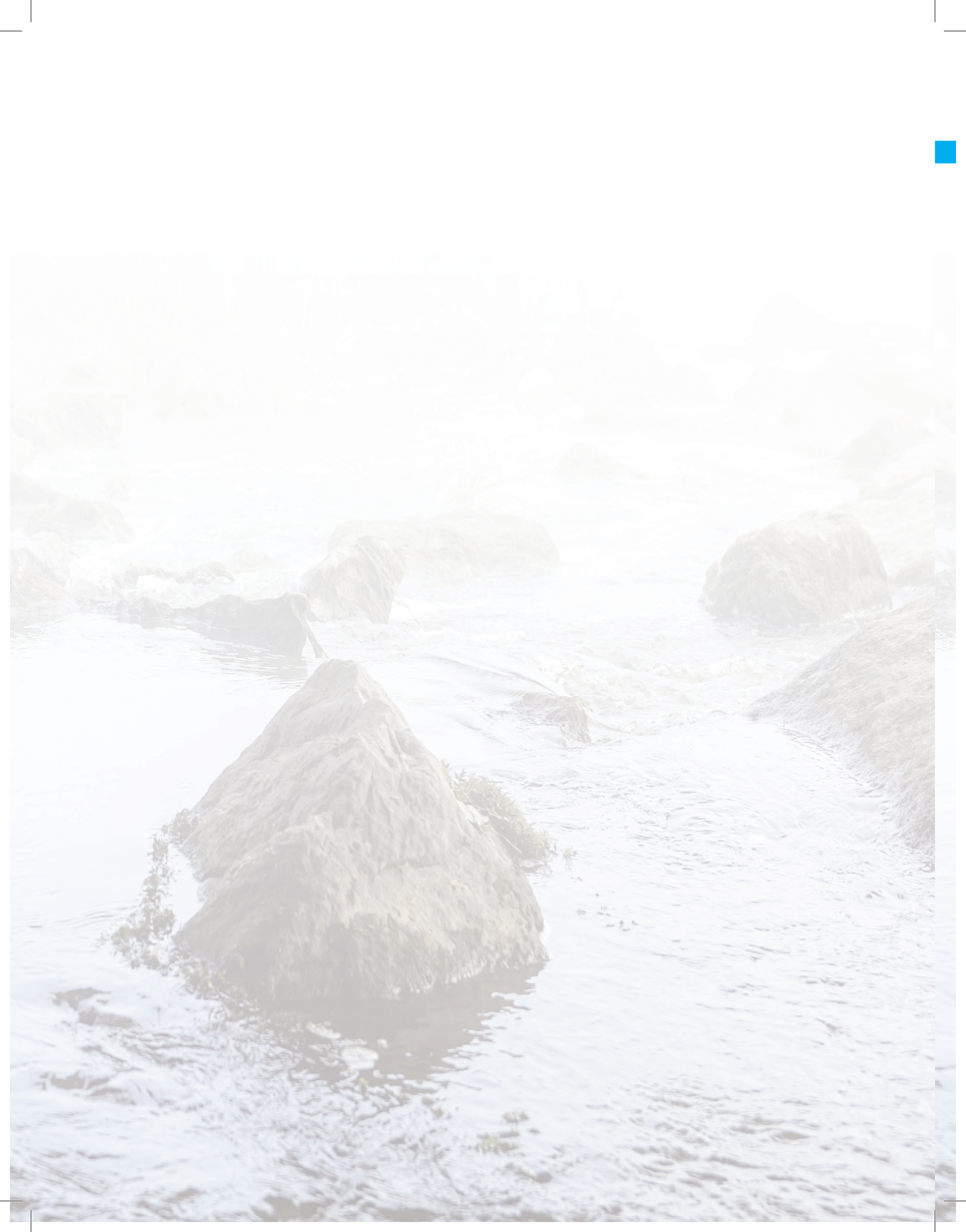
May this monograph serve as a guiding light for researchers, practitioners, and enthusiasts alike, illuminating the path towards a deeper appreciation of nature's pharmacy along the revered Ganga River.

With heartfelt gratitude and blessings,



- Swami Ramdev





PREFACE

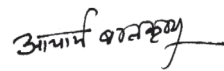
The Ganga River, revered as the lifeblood of India, flows through the heart of the country, nourishing not only the land but also the spirit of the people. It is not just a geographical entity; it is a symbol of life, purity, and sustenance. From its origin in the pristine glaciers of Uttarakhand to its expansive delta in West Bengal, the Ganga traverses diverse landscapes, each rich in its own unique flora and fauna. For centuries, it has supported a wide variety of ecosystems, each harbouring plant species that are integral to the ecological balance, cultural heritage, and traditional practices of the region. This monograph series is dedicated to exploring and documenting the indigenous plants that thrive along this sacred river, from the high-altitude regions of Uttarakhand to the fertile plains of West Bengal. These plants are not merely biological entities; they are part of the cultural and spiritual fabric of the communities that have lived along the Ganga for generations. They are used in traditional medicine, rituals, and daily life, and they play a crucial role in the local economies.

The journey from Uttarakhand to West Bengal covers a vast array of ecosystems, from the alpine forests of the Himalayas to the mangroves of the Sundarbans. At each of the 26 sites we studied, the selected plant species reflect the unique environmental conditions and cultural practices of the region. This series of monographs is a culmination of an extensive research initiative aimed at understanding and preserving the botanical wealth of the Ganga basin. A total of 26 key sites along the river, spanning the length from its source in Uttarakhand to its mouth in the Bay of Bengal, were explored, analysed, and documented. At each of these sites, the indigenous plant species were studied which are adapted to the unique environmental conditions present. The exploration focuses on ten plant species that are not only emblematic of the region but also hold significant ecological, medicinal, and cultural value.

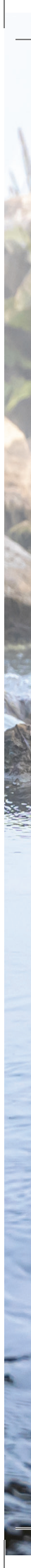
Each monograph in this series provides a comprehensive overview of the plant species, detailing its botanical characteristics, ecological role, traditional uses, and cultural significance. The data for distribution of these plants along the Ganga, highlighting the environmental factors that influence their growth and survival is primarily focussed. To achieve a comprehensive understanding, the selected sites were explored for their botanical diversity, phytochemical properties of the plants, and soil properties examination of each area. Additionally, *in silico* analysis was conducted to assess the plants' potential in combating several diseases. The study also investigated the ethnomedicinal and pharmacological uses and applications of these plants, complemented by a bibliometric analysis to evaluate existing research and knowledge. This exploration also presents as a fresh insight to classical literature of Ayurveda in the form of "Shlokas" and therefore extending beyond the identification of individual species; it adds a fresh perspective to the existing literature and delves into uncovering the intricate web of life that sustains these plants and the human communities that rely on them.

Patanjali Group recognized the critical need to explore the diverse botanical landscape of the Ganga River basin and to conduct scientific, evidence-based research to highlight its ecological and medicinal significance. With this vision, Patanjali Organic Research Institute embarked on an initiative to systematically document and analyse the indigenous plant species found across this region. The goal is to develop scientifically validated insights into the botanical diversity, phytochemical properties, and ethnomedicinal uses of these plants, thereby creating a comprehensive understanding of the current status and challenges associated with preserving this rich natural heritage.

We express our deepest gratitude to Param Pujya Swami Ramdev Ji for his unwavering leadership and support throughout this endeavour, as well as for his invaluable guidance in every aspect of our work. My best wishes to the dedicated and highly skilled experts, who have meticulously gathered data and conducted extensive research on the diverse botanical heritage of the Ganga River basin, utilizing cutting-edge scientific techniques and methodologies. Nature holds immense potential for sustainable practices and this project is a significant contribution to the preservation of these indigenous plant species, ultimately benefiting both ecological balance and the well-being of the communities that rely on them.



Dr. Acharya Balkrishna



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Classical Ayurvedic Insight

Ficus racemosa L.

Vedic name : (Payovṛkṣakaḥ udumbaraḥ) (पयोवृक्षकः उदुम्बरः)

Botanical name : *Ficus racemosa* L. Syn. *Ficus glomerata* Roxb.

Utpatti sthānam

Śrīlaṅkāyāñca nepāle cīne ca dakṣiṇe tathā.

Pākistāne tathā brahmadeśe prācyācca dakṣiṇe.

Eśiyādvīpataścāpi nyūginīkṣetrājātake.

Uttarāṣṭreliyaśe bhārata sakale kila.

Sahasrapuruṣoddeśe sarvadā harite vane.

Viśeṣatastu pañcāla utkale magadhe'pi ca.

Paścimavaṅgato rājasthāne ca dakṣiṇasthale.

Udumbaro sadā bhāti viṃśativyāmāmbitah. (Saumitreyā Mahodadhi: 1-4)

Distribution

In the world found in Nepal, Sri Lanka, Ethiopia, Pakistan, Myanmar, eastwards through southeast Asia to New Guinea, Northern Australia, Southern China. Throughout most of India it found to an elevation of about 2000 m in evergreen forests. It found mostly in Punjab, Bihar, Odisha, West Bengal, Rajasthan and South India. ^[1-4]

Vānaspatika vivaraṇam

1. Kāyika lakṣaṇam

Madhyamākārataścā'yaṃ bṛhadrūpastathaiva ca.

Aniyatena śīrṣeṇa yuktaśca sarvadā harit.

Athavā parṇapātīva praroḥo'romaśo'thavā.

Romaśo bhāti tasyaivaṃ kāṇḍatvak cikkaṇā tathā.

Raktābhadhūsaracchāyā pāṭalababhruvarṇataḥ.

Jīrṇaśākhāstu vidyante śālkajātena saṃyutāḥ.

Patramekāntaraṃ jālasadrkṣaṃ sūnyaromakam.

Pañcāṅgulocchritāt kvāpi vitastilambitantathā.

Sārdhāṅgulāyatāt tacca caturaṅgulakāyatam.

Aṇḍākāramadhovatrasaṃmitāṇḍakalevarāt.

Dīrghāyatantathā dīrghavṛttābhabhallakākṛti.

Upāntaḥ pūrṇato bhāti dhārāhīnena lambinā. (Saumitreyā Mahodadhi: 5-10)

Botanical Description

1. Vegetative Characters

A medium sized to large laticiferous evergreen or occasionally deciduous tree up to 30 m tall, often with an irregular, shabby crown. Shoots glabrous or pubescent. Bark smooth, pinkish brown to reddish grey, coarsely flaky on older trees. Leaves alternate, membranous, glabrous, 10-19 cm long and 3.2-8.5 cm wide, ovate, obovate-oblong or elliptic-lanceolate, margins entire, tapering to a bluntly pointed apex, base obtuse rarely acute, 3-nerved. Petioles 2.5-5 cm long, grooved, minutely hairy, brownish-scurfy. Stipules 1.2-2.5 cm long, 4-5 mm wide, ovate-lanceolate, pubescent, scarious. Cystoliths are present only on the lower side. ^[1-4]

2. Puṣpīya lakṣaṇam

Śīrṣeṇa ca samāyuktaṃ kramāt saṅkucitaṃ bhavet.
Ādhārastasya kuṇṭhāgrastīkṣṇāgraśca kadācana.
Tantrikātrayasampṛktaḥ parṇavṛntantu tatra vai.
Sapādāṅgulakocchrāyāt sārḍhadvyaṅgulalambitam.
Khātayuktantathā sūkṣmaromaśaṃ babhruvarṇataḥ.
Parpaṭīmayamābhāti tathā tatrā'nupatrakam.
Ardhāṅgulocchritāt kvāpi sapādāṅgulalambitam.
Triyavāyāmasampṛktaṃ jālābhaṃ romaśantathā.
Aṇḍābhabhallanīkāśaśarīraṃ pratibhāsate.
Aśmayābhaṃ tadīyañca sarvathā saṃbhavedadhaḥ.
Puṣpīyalakṣaṇe puṣpaṃ laghu puṣpālīvṛntayuk.
Pātradhānyāṃ virājeta prāyeṇa golakākṛti.
Pādonāṅgulakavyāsāt sārḍhadvyaṅgulavigraham.
Pāke tu svalparaktābhaṃ hrasvañca dīrghagucchake.
Parṇahīnantathā kīlayuktaśākhāsu saṃsthitam.
Tadeva stambhajīrṇāsu śākhāsu jāyate kila.
Ādhārasahapatrāṇi trīṇi santi ca tānyaho.
Aṇḍākāratrīkoṇīyaśarīrāṇi cakāsati.
Naratrīgālapuṣpāṇi pātradhānyāṃ viśeṣataḥ.
Yugapat sambhavantyatra nṛpuṣpaṃ śūnyavṛntakam.
Pātradhānīmukhe cā'sti trīṇi bāhyadalāni vai.
Catvāri kvāpi vidyante sadā jālamayāni ca.
Sphītāni ca parāgāṇāṃ dīrgharūpeṇa saṃsthitau.
Kośā āvṛtya tiṣṭhanti dvau tau puṃskesarau matau.

Puṁstantu sahaajāto'sti strīpuṣpaṁ śūnyavṛntakam.

Athavā prāyaśo vṛntahīnamatra vibhāvyate.

Bāhyadalaṁ nṛpuṣpeṇa sadṛśaṁ pratibhāsatē.

Aṇḍāśayastathā prāyaśchatrakākāravigrahaḥ.

Pārśviko dviyavottuṅgo'romaśavartikāyutaḥ.

Tadagraṁ saralaṁ bhāti gālapuṣpaṁ savṛntakam.

Bījantu vātarandhreṇa yuktañcāpi yavocchritam.

Hemante kusumodbhūtiḥ phalañca caitramāsataḥ. (Saumitreya Mahodadhi: 11-26)

2. Floral Characters

Flowers present in shortly pedunculate receptacles, subglobose, dense tomentose, 1.5-3 cm in diameter, dull reddish when ripe, borne in large clusters on short, leafless warty branches arising from the trunk and older branches. Basal bracts 3, ovate-triangular. Male, female and gall flowers together in on receptacle. Male flower sessile, situated near the mouth of the receptacles. Sepals 3-4, membranous, inflated, enveloping the 2 elongate ovate anthers. Stamens 2. Filaments connate. Female flowers sessile or subsessile. Sepals as in male. Ovary sub-stipitate, with lateral, 2.3 mm long, glabrous style. Stigma simple. Gall flowers pedicellate, dispersed among female. Seeds lenticular, 1 mm long. Flowering December-January. Fruiting March-June. ^[1-4]

Plant Anatomy

Prayojyāṅgam

Payovṛkṣakasamjijñasyodumbarasya pracoditam.

Prayojyāṅgaṁ tvacābhāgastadantāracanocyate. (Saumitreya Mahodadhi:1)

Antaḥsamracaneḥṣaṇe

(a) Śuṣkatvak

Ṣaṭkalpataḥ starīyo'sya tvakprotako'bhidṛśyate.

Kośikāstanubhittīyā babhruvarṇā bhavanti ca.

Tvakprotakaidhikā labhyā hyekastarānvitā tathā.

Dvītīyakākhyakā majjakośā dvādaśakalpataḥ.

Starānvitāḥ samādrśyāstanubhittimayāstathā.

Kośikā āyatākārā niyataṁ nirmitā iha.

Majjakośe dvītīyākhye drśyā maṇḍakaṇāstathā.

Cūrṇātukṣāarakasyātra samāsamāḥ kaṇā iha.

Kośikā bahulāḥ parṇahārityena prapūritāḥ.

Hārityābhāsa ābhirvai jāyate'tra yathāyatham.
 Pragolākārato majjakośikā dīrghakā yathā.
 Kośikāstanubhittiyā nāraṅgavarṇasannibhāḥ.
 Babhruvarṇapadārthairvā samāyuktā bhavanti ca.
 Bahulāḥ kośikāstatra saralā bhānti tattvataḥ.
 Yuktairmaṇḍakaṇairyuktā cūrṇātukṣārakasya ca.
 Kaṇaiḥ prapūritā dṛśyāḥ poṣavāhā dvitīyakāḥ.
 Cālanīnālikāgucchaiḥ saṃyuktā mṛdulāstathā.
 Te sahakośikāvrāte vinirmittā bhavanti ca.
 Mṛdulāḥ poṣavāhāśca golākārasvarūpataḥ.
 Aṇḍākārā ihālokyāstanubhittimayāstathā.
 Tantavaḥ poṣavāhāṇāṃ kośikāvicchadairyutāḥ.
 Pralambā atha ca dvitrastarānvitāśca kośikāḥ.
 Tanubhittīyakāḥ sparśarekhāyuktā bhavanti ca.
 Ityevaṃ kṣīriṇaḥ proktāntāracanā yathekṣitam. (Saumitreya Mahodadhi: 2-13)

Plant Parts

Dried Bark

Microscopic Characters

Bark

Cork is 3-6 layered, thin-walled cells filled with brownish content. Cork cambium is single layered. Secondary cortex is 6-12 layered and composed of thin-walled rectangular cells arranged regularly. Secondary cortex cells contain starch grains, and some contain rhomboidal crystals of calcium oxalate. Most of cells are filled with chloroplast giving green appearance. Cortex is composed of circular to oblong, thin-walled cells, containing orange-brown content. Most of the cells are filled with simple and compound starch grains and crystals of calcium oxalate. Secondary phloem is composed of parenchyma with patches of sieve tubes and companion cells. Phloem parenchyma is circular to oval and thin walled. Phloem fibres are elongated and lignified. Cambium is 2-3 layered tangentially elongated thin-walled cells. [1, 5-7]

Medicinal Uses

Ophthalmic disorders

Udumbaraphalaṃloheghṛṣṭaṃstanyenadhūpitam.
 Sājayaiḥsamīchadairdāhaśūlarāgāśruharṣajit.(A.H.U. 16:36)

Eye disorders- Application of collyrium prepared from unripe fruit of *Ficus racemosa* (Cluster fig tree) triturated with cow milk is useful in treating eye disorders. ^[8](As.Hr.Ut. 16:36)

Nasal disorders

Udumbarāṇipakvānigūḍenamadhunā'pivānighnantināsārattaphaṁṇṇāṁdhruvam.
(Rā-Mā- 4:3)

Epistaxis- Intake of ripen *Ficus racemosa* (Cluster fig tree) fruit along with honey or jaggery is useful in treating epistaxis. ^[9] (Ra.Ma. 4:3)

Thoracic disorders

.....bhasmaudumbaram.....
...kṣaudropetaṁhantīḍhvā"śuhikkām. (Su.Ut, 50:21-22)

Hiccup- Intake of *Ficus racemosa* (Cluster fig tree) bark ash mixed with honey alleviates hiccup. ^[10] (Su.Ut. 50:21-22)

Abdominal disorders

Pittajāyāṁsitāyuktaḥpakvodumbarajorasah.
Ratkvāthovāhimaḥ.....(A.Hr.Ci. 6:69)
Paryāgatodumbarajorasastusaśarkarastatkvathitodakamvā.(Su.U. 48:22)

Hyperthirst- Intake of *Ficus racemosa* (Cluster fig tree) ripen fruit juice mixed with cold infusion or decoction alleviates hyperthirst. ^[8] (As.Hr.Ci. 6:69), ^[10] (Su.Ut. 48:22)

Nyagrodhodumbarāśvatthaśugaṅgānāpothyavāsayet.
Ahorātraṁjaletapteghṛtaṁtenāmbhasāpacet.
Tadardhaśarkarāyuktaṁlihyātsakṣaudrapādikam.
Adhovāyadivā'pyūrdhvaṁyasyaraktaṁpravartate. (Ca.Ci.19:99-100)

Diarrhea- Intake of *Ghrita* (Clarified butter) processed with *Ficus benghalensis* (Banyan tree), *Ficus racemosa* (Cluster fig tree) and *Ficus religiosa* (Peepal tree) infusion mixed with sugar and honey is useful in treating bloody diarrhea and *Raktapitta*. ^[11] (Ca.Ci. 19:99-100)

Udumbaraśalātūnisvinnānījalavāṣpataḥ.
Dadhnāvinīyabhuñjītagrahaṇīglapitonaraḥ.(Si.Bhe.Ma.Caturthaguccha, Grahaṇī ci. : 2)

Sprue- Intake of steamed fruit of *Ficus racemosa* (Cluster fig tree) mixed with curd is useful in treating sprue. ^[12] (Sd.Bh.Mm. Ch. Gr.Ci. :2)

Nārīstanyenasamṣyuktāṁpibedaudumbarītvacam.
Tābhyāṁvāpāyasaṁsiddhamadyādatyagnīśāntaye.(Ca.Ci. 15:230)

Bhasmaka- Intake of *Ficus racemosa* (Cluster fig tree) bark paste along with milk is useful in treating *Bhasmaka* (polyphagia). ^[11] (Ca.Ci. 15:230)

Reproductive system disorders

Udumbarasyadugdhenashaṭkṛtvobhāvitāttilāt.

Tailamkvāthenatasyaivasiddhamdhāryam ca pūrvavat. (Ca.Ci. 30-77)

Venereal disorders- Insertion of vaginal suppository prepared from *Ficus racemosa* (Cluster fig tree) latex, *Sesamum indicum* (Sesame) oil and *Ficus racemosa* (Cluster fig tree) decoction is useful in treating vaginal disorders. ^[11] (Ca.Ci. 30:70)

Udumbaramśalātūnāmdroṇamadroṇasamṃyuta.

Sapañcavalkakulakamamālatīnimbapallavam.

Picchilāvivr̥tākāladuṣṭāyonīscadāruṇā.

Saptāhācchudhyatikṣipramapatyaṃcāpivindati. (Ca.Ci.30: 73-77)

Insertion of vaginal suppository prepared from *Ficus racemosa* (Cluster fig tree) oil is useful in treating vaginal disorders. ^[11] (Ca.Ci. 30:73-77)

Kṣaudrayuktaṃphalarasamaudumbarabhavaṃpibet.

Asrgdaravināśāyasaśarkarapayo'nnabhuk. (Bhā.Pra.Ci. 68:16)

Metrorrhagia- Intake of unripe *Ficus racemosa* (Cluster fig tree) fruit juice mixed with honey and intake of sugar added milk and rice is useful in treating metrorrhagia. ^[13] (Bh.Pr.Ci. 68:16)

Udumbarakvāthayutaṃsitāḍhyaṃsugandhiśālīprabhavaṃsitam ca.

Yāpiṣṭamaśnātinagarbhapaṭapīḍāmasauvindatijātunārī. (Rā.Mā. 31:21)

Abortion- Intake of rice paste along with *Ficus racemosa* (Cluster fig tree) decoction and crystal sugar is useful in treating the pain caused due to an abortion. ^[8] (Ra.Ma. 31:21)

Udumbaraphalaudakakandakvāthenavāśarkarāmadhumadhureṇaśālīpiṣṭam.
(Su.Śā. 10:57)

Intake of decoction prepared from *Ficus racemosa* (Cluster fig tree) and *Nelumbo nucifera* (Lotus) mixed with *Śālīdhānya* and honey is useful in preventing an abortion. ^[10] (Su.Sh. 10:57)

Carma.....udumbarasyavā.

Piṣṭamtuṣāmbunāpītamaparāṃpātayetkṣaṇāt. (Vai.Ma. 13:37)

Afterbirth (Placental expulsion)- Intake of *Ficus racemosa* (Cluster fig tree) bark pounded with rice water is useful for afterbirth. ^[14] (Vd.Mn. 13:37)

Bandākamaudumbaramādareṇavandhyāṅganāpuṣpaviśuddhivāre.

Pūrvamviriktālabhatekumāraṃchāgasyadugdhenasahaprapītvā. (Vai.Ma.13:11)

To promote conception- Intake of *Ficus racemosa* (Cluster fig tree) and *Dendrophthoe falcata* (Mistletoe) pounded with goat milk is useful to promote conception. ^[14] (Vd.Mn. 13:11)

Palāśodumbaraphalaṃtilatāilasamanvitam.

Madhunāyonimālipyagāḍhīkaraṇamuttamam. (Vaṃ.Se. Strīroga : 296)

Vaginal disorders- Topical application of paste prepared from *Ficus racemosa* (Cluster fig tree) and *Butea monosperma* (Flame tree) fruit pounded with honey and *Sesamum indicum* (Sesame) oil is useful in treating vaginal disorders. ^[15] (Vg.Sn. St.Rg. :296)

Udumbaraśikhākvāthekṣīraṃsamadhuraśarkaram.

Śālīṃpiṣṭvāpibedbharbhavinipātanivartanam. (Vai.Ma. 13:16)

Abortion- Intake of *Ficus racemosa* (Cluster fig tree) root decoction mixed with milk, honey, sugar and *Śālīdhānya* is useful in preventing an abortion. ^[14] (Vd.Mn. 13:16)

Disorder of extremities

Udumbaraṣṭrayutaṃsvaguptāmūlaṃsamaṃjīṅṇikārasena.

Sarāmaṭhaṃhantyaavabāhukākhyamṇasyaprayogātpuruṣasyarogam.
(Ga.Ni.Śa.Taṃ. 1: 116)

Stiffness in the arm- Snuff of powder prepared from *Mucuna pruriens* (Cow hage) root, *Lannea coromandelica* (Indian ash tree) juice and *Ferula narthex* (Asafoetida) triturated with *Ficus racemosa* (Cluster fig tree) latex is useful in alleviating the stiffness of arm. ^[16] (Gd.Ni. Sh.Tn. 1:116)

Dermatological disorders

Jantuphalavalkamadhyamkalkīkṛtyakilasurabhimūtreṇa.

Vidhivadbaddhānamgambhīrādṛṣṭānāḍikāśāntyai.
(Si.Bhe.Ma.Caturthaguccha, Nāḍīvraṇa ci. : 15)

Wound- Topical application of *Ghrita* (Clarified butter) fried *Ficus racemosa* (Cluster fig tree) bark paste pounded with cow urine is useful in treating chronic wound. ^[12] (Sd.Bh.Mm. Ch. Nd.Vr.Ci. :15)

Generalised body disorders

Pakvodumbarakārśmayapathyākharjūrāgostanāḥ.

Madhunāghnantisaṃlīḍhārāktapittamṛthak-ṛthak. (Vr.Mā. 9:23)

Raktapitta- Intake of ripen *Ficus racemosa* (Cluster fig tree) juice mixed with honey is useful in treating *Raktapitta*. ^[17] (Vr.Ma. 9:23)

Udumbaraphalaṃpiṣṭvāpibettadrasamevavā. (Su.U. 45:23)

Intake of *Ficus racemosa* (Cluster fig tree) fruit is useful in treating *Raktapitta*. ^[10] (Su.Ut. 45:23)

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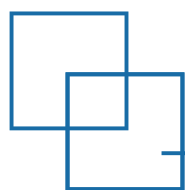
Abbreviation

A.Hṛ.Ci.	:	AṣṭāṅgaHṛdayaCikitsā
A.Hṛ.U.	:	AṣṭāṅgaHṛdaya Uttara Tantra
As.Hr.Ut.	:	AṣṭāṅgaHṛdaya Uttara Tantra
Bhā.Pra.Ci.	:	BhāvaprakśaCikitsā
Śā.Sa.Ut.Kha.	:	ŚāraṅgadharaSamhitā Uttara Khaṇḍa
Ca.Ci.	:	Caraka SamhitāCikitsāSthāna
Ca.Da.Ci.	:	CakradattaCikitsā
Ca.Si.	:	Caraka Samhitā Siddhi Sthāna
Ca.Sū.	:	Caraka SamhitāSūtraSthāna
Ck.Dt.Ci.	:	CakradattaCikitsā
Ga.Ni.Kā.Ci.	:	GadanigrahaKāyacikitsā
Ga.Ni.Kau.Taṃ.	:	GadanigrahaKaumaryatantra
Ga.Ni.Śā.Ta.	:	GadanigrahaŚālākya Tantra
Ga.Ni.Śa.Taṃ.	:	GadanigrahaŚalyatantra
Hā.Sa.	:	HārāitaSamhitā
Hā.Saṃ.	:	HārāitaSamhitā
Kā.Saṃ.Khilasthāna	:	KāśayapaSamhitāKhilasthāna
Rā.Mā.	:	RājaMārtaṇḍa
Ra.Ra.Sa.	:	Rasa Ratna Samuccaya
Śā.Ni.Guḍūcyādivarga	:	ŚāligrāmaNighaṇṭuGuḍūcyādivarga
Śā.Sa.U.Kha.	:	ŚāraṅgadharaSamhitā Uttara Khaṇḍa
Śā.Saṃ.Ma.Kha.	:	ŚāraṅgadharaSamhitā Madhyam Khaṇḍa
Sd.Bh.Mm. Ch. Gr.Ci.	:	Siddha BheṣajaMaṇimālāCaturthaGucchaGrahaṇāiCikitsā
Sd.Bh.Mm. Ch. Nd.Vr.Ci.	:	Siddha BheṣajaMaṇimālāCaturthaGuccha Nāḍāivraṇa Cikitsā
Sd.Bh.Mm. Ch.Nt.Rg.	:	Siddha BheṣajaMaṇimālāCaturthaGuccha Netra RogaCikitsā
Sd.Bh.Mm.Ch. Ars.Ci.	:	Siddha BheṣajaMaṇimālāCaturthaGucchaArśaCikitsā
Sd.Bh.Mm.Ch. Vrn.Ci.	:	Siddha BheṣajaMaṇimālāCaturthaGucchaVraṇaCikitsā
Sh.Gr.Ng. Gd.Vg.	:	ŚāligrāmaNighaṇṭuGuḍūcyādivarga
Su.Ci.	:	SuśrutaSamhitāCikitsāSthāna

Su.Ka.	:	SuśrutaSamhitā Kalpa Sthāna
Su.Śā.	:	SuśrutaSamhitāSārīraSthāna
Su.Ut.	:	SuśrutaSamhitā Uttara Tantra
Vai.Jī. Caturthavilāsa	:	Vaidya JāivanamCaturthavilāsa
Vai.Jī. Dvitīyavilāsaḥ	:	Vaidya JāivanamDvitīyavilāsaḥ
Vai.Ma.	:	Vaidya Manoramā
Vaṃ. Se. Āmavātarogādhikāraḥ	:	VaṃgasenaSamhitāĀmavātarogādhikāraḥ
Vaṃ.Se. Vātavyādhidhikāraḥ	:	VaṃgasenaSamhitāVātavyādhidhikāraḥ
Vaṃ.Se.Karṇarogaḥ	:	VaṃgasenaSamhitāKarṇarogādhikāraḥ
Vaṃ.Se.Medarogaḥ	:	VaṃgasenaSamhitāMedorogādhikāraḥ
Vaṃ.Se. Netrarog	:	VaṃgasenaSamhitāNetrarogādhikāra
Vaṃ.Se. Śothādhikāraḥ	:	VaṃgasenaSamhitāŚothādhikāraḥ
Vaṃ.Se. Strīrogaḥ	:	VaṃgasenaSamhitāStrīrogaḥ
Vaṃ.Se.Vātavyādhīḥ	:	VaṃgasenaSamhitāVātavyādhidhikāraḥ
Vṛ.Mā.	:	Vṛndamādhava

CHAPTER
01

Plant Exploration and Botanical Study



INTRODUCTION

Water is the key resource required to sustain life on this planet. It is found in most of the earth as in the ocean, rivers, ponds, streams, ice, etc. The river Ganga is an important source of water in India that makes an important river system from the Himalaya to the Bay of Bengal. The Indian civilization and economy depend on this river system due to its water availability throughout the year (Paul and Sinha, 2013). The river Ganga alone accounts for 25% of India's total water resources (Paul, 2017). Globally more than 300 million people from India, Nepal, and Bangladesh depend on the river Ganga (Gopal, 2000). This is the thirtieth longest river in the world and covers a basin area of 861,404 km² (Rahaman, 2009a). This basin is the most populated area in the world with an average density of 520 persons/km² (Das and Tamminga, 2012). The basin is very rich in heritage, cultural, and religious values. India's about one-fourth area drains by the river Ganga.

The river originates from the Gangotri glacier at Gomukh (30° 36' N; 79° 40' E; 3800 m) in the Uttar Kashi district of Uttarakhand under the name of Bhagirathi; and another tributary *i.e.*, Alaknanda which is originated from the Bhagirath-Kharak (30° 49' N; 79° 17' E) and Satopanth (30° 45' N; 79° 21' E) glaciers. Both the tributaries join at Devprayag from where the name Ganga started. The river has a total length of 2600 km from its main source Gomukh.

Up to Haridwar, it flows in the hills after here it enters the plain area. From here, it flows southwards, passing through the plains of Uttar Pradesh starting from Bijnor district. Up to Ballia it continuously flows in Uttar Pradesh through different districts after here it enters Bihar near Chausa of Buxar district. It flows up to Katihar district in Bihar and from here it enters the Sahebganj district of Jharkhand. Then it turns southwards and enters the West Bengal from the Murshidabad district. About 40 km from the Farakka, it divides into two streams; the left stream flows eastwards toward Bangladesh while the right stream, known as Bhagirathi, continues to flow south through West Bengal. Its name changed to Hooghly when it flows in the west and south-west of Kolkata. The Hooghly at Diamond Harbor flows southward and is split into two streams before reaching the Bay of Bengal (Rahaman, 2009b).



The annual water discharge from the river Ganga is about 18700 m³/s which is the fifth highest in the globe (Paul, 2017). The maximum flow of the Ganga exists within the catchment area with a mean maximum flow is 468.7×10^9 m³ which is a total of 25.2 % of the total water resources of India (Sarkar et al., 2012). The main source of the river Ganga is the melting of snow in the Himalayas and monsoon rains. The water of the Ganga is regularly used by the living being for drinking. Outdoor bathing has a spiritual significance for Hindus in which millions of people take a holy dip at least once a year throughout the course of the river, from Gangotri to Ganga Sagar.

The Ganga basin supports biodiversity, species richness, and uniqueness, attracting people from different parts of the earth. Plant communities have been a major magnetism for investigation since time immemorial. Vegetation composition and assemblages of an area form a significant habitat that contributes to the structure and function of such ecosystems. The vegetation pattern along the Ganga varies according to the seasonal changes, flood level, and species composition differs by the function of water supply and different soil types, which has a sharp influence on plant species distribution. Macrophytes such as submerged, emergent, and free-floating aquatic plants are known to accumulate and bioconcentrate heavy metals producing an internal concentration several folds greater than their surroundings (Chen et al., 2008; Allen-Diaz et al., 2008). The river basin has large numbers of medicinal plant species. The natives depend on the river for water and medicinal importance to fulfill their requirements from the beginning.

Among all the medicinal plants, the *Ficus racemosa* was considered in this study. It is commonly known as 'cluster fig', 'red river fig', or 'gular' which is a fast-growing plant with large, very rough leaves, usually attaining the size of a large shrub, although older plant can grow quite large and gnarled. It grows profoundly in open lowland deciduous forests, and common along riverbanks. It is a buttressed, deciduous cauliflorous tree that reaches a height of 20 to 30 metres. Its crowns are frequently uneven. Infructescences in big clusters on branching. Fruit a fig, pyriform to subglobose, rose-red when ripe. Edible figs may be used in a variety of preserves and side dishes. It is anti-diarheal in medicinal form. Water-resistant paper is made using its latex. On this basis, the current chapter is focused on the morphology, taxonomy, anatomy, and distribution assessment of *F. racemosa* around the Ganga River.

Genus *Ficus* Tourn. ex L.

The genus *Ficus* was first described by Linnaeus in 1753 in *Genera Plantarum* with only seven species. *Ficus* is a genus of more than 800 species that account for more than half of the species diversity of the mulberry family, Moraceae (Clement et al., 2020). Currently, around 511 species of the *Ficus* occur in the Indo-Australasian region (Asia, Malesia, Pacific islands and Australia) and around 132 in the Neotropical region (Central and South America). In the Afrotropical region (Africa south of the Sahara, including Madagascar) there are currently 112 recognized species, 36 of which are indigenous to southern Africa (25 species in South Africa) (Kumar et al., 2018; Kumar et al., 2021). It is native to the Tropical and Subtropical regions of the world and includes trees, hemiepiphytes, epiphytes, shrubs, climbers, rheophytes, and lithophytes. The maximum concentration of this genus found in the Asian-Australian region which is around 66% of the world's species. Large numbers of species are very common in different biogeographic regions. Maximum numbers of species grow in the lowlands, but some of them reach up to about 2000 m altitude. The Asian species of *Ficus* have been worked out by Corner (1965).

In India, firstly Roxburgh in 1832, included a total of 55 species from India in his book "*Flora Indica*". King (1887-88, 1888) presented the taxonomic account of the Indian *Ficus* and mentioned 113 species and 47 infraspecific taxa from the whole of British India out of

which only 75 species and 16 infraspecific taxa were reported from the present political boundary of India. Later on, various works have been carried out either at regional or global levels (Duthie, 1915; Corner, 1958, 1965, 1969, 1975, 1981; Yamazaki, 1983; Berg, 1989, 2001, 2003, 2004 a,b; Liao, 1996; Kochummen 1998; Chang and Wu, 1998; Dixon, 2003; Wu et al., 2003; Burrows and Burrows, 2003; Tzeng, 2004; Berg and Corner, 2005; Tzeng, et al., 2009, Chaudhary et al., 2012; Chantarasuwan et al., 2013; Tiwari et al., 2014). It is the most diversified genera in terms of its habits and life forms because it has a vast distribution pattern throughout the country, among all biogeographic zones (Chaudhary et al., 2012). King's book "Magnum opus on Indo-Malayan figs" published in 1887 was the first to describe over 220 species with superb plates. Subsequently, Hooker (1888) identified 112 species from the Indian subcontinent, which included Bangladesh and Pakistan. Fischer (1928) provided a succinct overview of 30 species of *Ficus* for the former Madras Presidency. The significance of *Ficus* is documented in ancient literature dating back to 256 B.C. According to legend, the Buddha attained enlightenment under the *Ficus* tree over 2500 years ago (Gadgi, 1996).

Due to the fruits of the genus being consumed year-round by insects, birds, and mammals, it is regarded as a keystone species and plays an extremely important function in the ecosystem. Decomposers utilise the fallen

figs, which increases the fertility and organic matter in the soil. Figs are an essential food source and part of the life cycle for many insect and wasp species. *Ficus* trees are also thought to be among the hosts of Indian lac insects. Humans also employ fig fruits in a variety of delectable cuisines due to their high nutritional content. Elephants and other livestock graze on the leaves of several *Ficus* species. Rubber and several other products, including jam and rope, are produced commercially from some of these species (Anonymous, 1956; Kirtikar and Basu, 2001). Furthermore, throughout ancient times, the Indian populace has strong religious beliefs about some *Ficus* species.

Etymology

The generic name, *Ficus* was proposed by Linnaeus in 1753. The Latin name '*Ficus*' comes from the Indian word "Fag", which was pronounced as "Figs" in Italian, Portuguese, and Spanish, as well as "Figsee" in French, "Feigen" in German, and "Rijig" in Dutch. The Persian word 'fica' or the Hebrew word 'fag' is where the term "fig" originated, and it was first used in English in the 13th century (Kumar et al., 2021).

Habitat and Distribution

The genus *Ficus* is extensively spread in tropical and subtropical regions of the world that frequently experience cold desert. It has been extended from the southern United States via Central America and the Caribbean

to North Argentina, and from Asia Minor, South China, and Japan to the Tuamotu Archipelago via Africa, Asia, Australia, and Polynesia (Corner, 1958). According to the Plants of the World Online database (POWO, 2023), this genus is native to the Afghanistan, Aldabra, Algeria, Andaman Is., Angola, Argentina Northeast, Argentina Northwest, Aruba, Assam, Bahamas, Bangladesh, Belize, Benin, Bermuda, Bismarck Archipelago, Bolivia, Borneo, Botswana, Brazil North, Brazil Northeast, Brazil South, Brazil Southeast, Brazil West-Central, Burkina, Burundi, Cabinda, Cambodia, Cameroon, Cape Provinces, Cape Verde, Caprivi Strip, Caroline Is., Cayman Is., Central African Repu, Central American Pac, Chad, China North-Central, China South-Central, China Southeast, Christmas Is., Cocos (Keeling) Is., Colombia, Comoros, Congo, Cook Is., Costa Rica, Cuba, Cyprus, Djibouti, Dominican Republic, East Himalaya, Ecuador, Egypt, El Salvador, Equatorial Guinea, Eritrea, Ethiopia, Fiji, Florida, French Guiana, Gabon, Gambia, Ghana, Gilbert Is., Greece, Guatemala, Guinea, Guinea-Bissau, Gulf of Guinea Is., Gulf States, Guyana, Hainan, Haiti, Honduras, India, Iran, Iraq, Ivory Coast, Jamaica, Japan, Jawa, Kazan-retto, Kenya, Korea, Kriti, KwaZulu-Natal, Laccadive Is., Laos, Lebanon-Syria, Leeward Is., Lesser Sunda Is., Liberia, Libya, Line Is., Madagascar, Malawi, Malaya, Maldives, Mali, Maluku, Marianas, Marquesas, Marshall Is., Mauritania, Mauritius, Mexican Pacific Is., Mexico Central, Mexico Gulf, Mexico Northeast, Mexico Northwest, Mexico Southeast, Mexico Southwest, Mozambique,

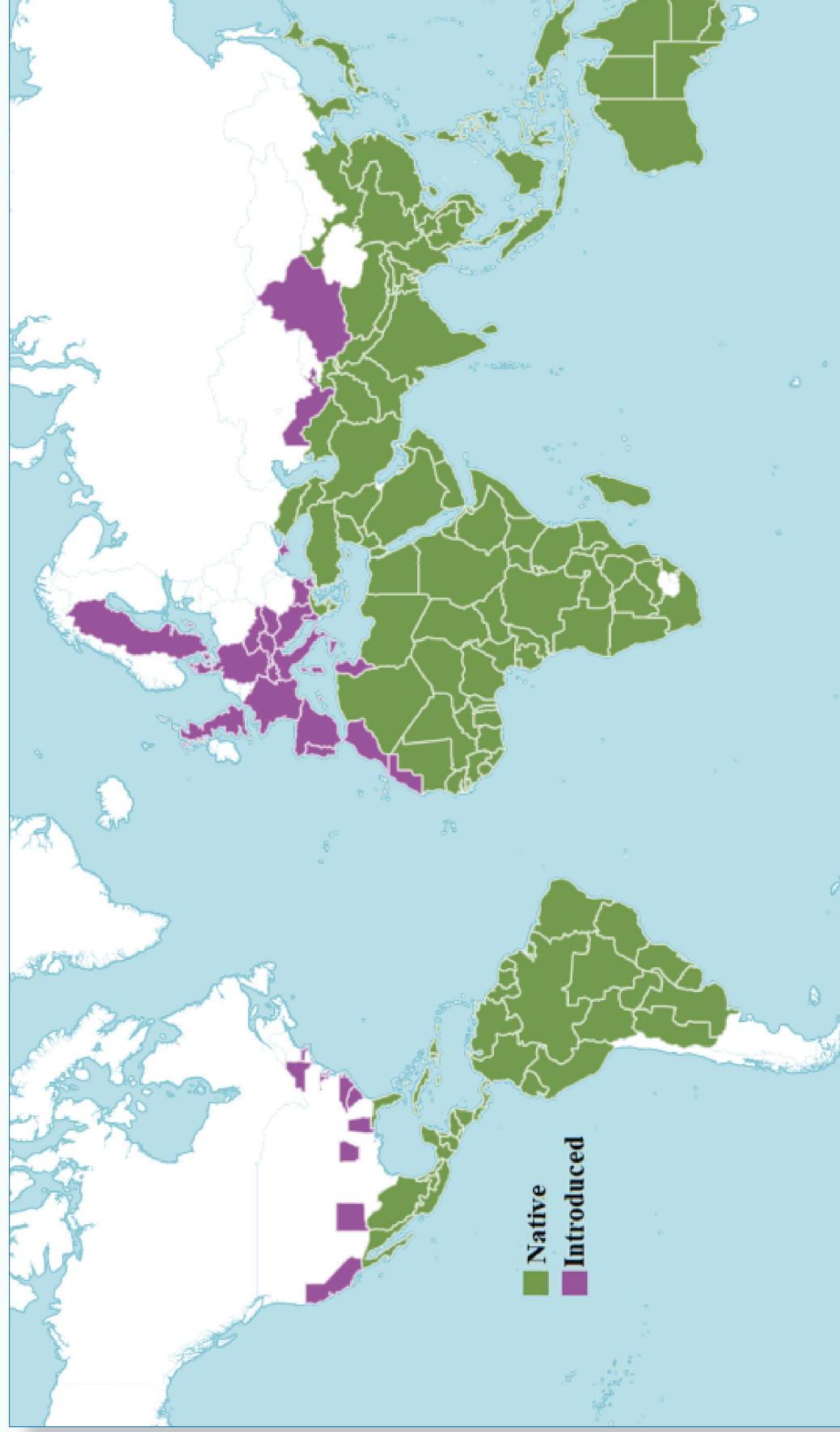


Fig. 1 Global distribution of genus *Ficus*

Myanmar, Namibia, Nansei-shoto, Nauru, Nepal, Netherlands Antilles, New Caledonia, New Guinea, New South Wales, Nicaragua, Nicobar Is., Niger, Nigeria, Niue, Norfolk Is., North Caucasus, Northern Provinces, Northern Territory, Ogasawara-shoto, Oman, Pakistan, Palestine, Panamá, Paraguay, Peru, Philippines, Pitcairn Is., Puerto Rico, Queensland, Rodrigues, Rwanda, Réunion, Samoa, Santa Cruz Is., Saudi Arabia, Senegal, Seychelles, Sierra Leone, Sinai, Society Is., Socotra, Solomon Is., Somalia, South Australia, South China Sea, Southwest Caribbean, Sri Lanka, Sudan, Sulawesi, Sumatera, Suriname, Swaziland, Tadzhikistan, Taiwan, Tanzania, Thailand, Tibet, Togo, Tokelau-Manihiki, Tonga, Transcaucasus, Trinidad-Tobago, Tuamotu, Tubuai Is., Turkey, Turkmenistan, Turks-Caicos Is., Tuvalu, Uganda, Uruguay, Vanuatu, Venezuela, Venezuelan Antilles, Victoria, Vietnam, Wallis-Futuna Is., West Himalaya, Western Australia, Windward Is., Yemen, Zambia, Zaire, Zimbabwe; while it is introduced in the Alabama, Albania, Arkansas, Ascension, Austria, Azores, Balears, Bulgaria, California, Canary Is., Chagos Archipelago, Corse, Czechoslovakia, Denmark, East Aegean Is., Easter Is., France, Galápagos, Germany, Great Britain, Hawaii, Hungary, Italy, Juan Fernández Is., Krym, Madeira, Maryland, Massachusetts, Morocco, New Mexico, New York, New Zealand North, New Zealand South, North Carolina, Portugal, Sardegna, Sicilia, South Carolina, Spain, St. Helena, Sweden, Switzerland, Tristan da Cunha, Tunisia, Turkey-in-Europe, Uzbekistan, Wake Is., Western Sahara, Xinjiang, Yugoslavia (Fig. 1).

Botanical Characteristics

Trees, shrubs, sometimes climbers, epiphytes; evergreen or deciduous, with milky sap. Monoecious or dioecious. Terminal buds surrounded by pair of connate stipules, stipules are connate, caducous, fused. Leaves alternate, rarely opposite or verticillate, monomorphic (dimorphic in *F. pumila*), margins entire, rarely dentate, palmate, lobed in *F. carica*, glabrous or hairy, wax glands in abaxial side with or without papillalike cystoliths, venation pinnate or nearly palmate. Inflorescences small, axillary or on specialized cauliflorous branches borne on inner walls of fruitlike and fleshy receptacle (syconium or fig). Syconia globose to pyriform with many minute flowers inserted on inner wall of hollow receptacle communicating with outside through an apical pore or apical pore closed by scale-like bracts, sessile or pedunculate; involucre bract usually 3 at base of fig, lateral bracts sometimes present on side of fig, scale-like, caducous, or persistent. The monoecious species with male, gall (sterile female), and female flowers in each fig while the dioecious with either male and gall flowers or only female flowers in each fig. Male flowers sessile or pedicellate, calyx of 2-6 sepals, stamens 1-3, straight, pistillode present or absent. Female flowers sessile, calyx lobes 0-6, ovary unilocular, free, straight or oblique; style unbranched, 1-2, unequal, apical lateral. Gall flowers similar to female flowers but never producing seeds and usually occupied by a fig wasp. Fruit achenes, enclosed within syncarp formed from an enlarged

hollow fleshy receptacle. Seeds pendulous; endosperm usually scanty; cotyledons equal or unequal, sometimes folded.

Ethnomedicinal Importance

Since ancient times, the *Ficus* genus has been used for a wide variety of culinary and medicinal purposes. The therapeutic use of figs is well documented in Ayurvedic and Traditional Chinese Medicine (TCM), particularly among populations where figs are native. The majority of the genus's species are employed in conventional medicine. Parts of *F. carica* and *F. sycomorus* are used to treat inflammatory tumors and illnesses. The stem bark of the *F. carica* plant is used medicinally in Africa to treat inflammatory, circulatory, pulmonary, and gastrointestinal conditions (Olaoluwa et al., 2022).

The fruits of *F. carica* are edible and may be used as food also uses as an antipyretic, aphrodisiac, lithontriptic, hair-nutritive, emollient, demulcent, and laxative. They can also be used to treat inflammations, paralysis, liver illnesses, chest discomfort, piles, leprosy, and nose bleeding (Shukranul et al., 2013). One of the most significant parts of the *Ficus* plant with medicinal use is the latex. Many indigenous people employ the latex from *F. carica* as an expectorant, diuretic, anthelmintic, anemia, and as a curdling agent for making the famous dairy product cheese (Badgujar et al., 2014).

Another crucial component of the plant with therapeutic qualities is the leaf. *F. carica* leaves are utilized to treat

inflammatory, pulmonary, gastrointestinal, and cardiovascular conditions (Shukranul et al., 2013). The roots of plants are the part that has been utilized to cure a wide range of illnesses. *F. carica* roots are used to treat cancer, inflammatory conditions, ulcerative illnesses, reflux, diarrhea, sore throats, coughs, bronchial issues, and cardiovascular abnormalities (Rubnov et al., 2001; Gilani et al., 2008). A comprehensive analysis of Indian *Ficus* was presented by Singh and Sharma (2023), addressing the significance of the diverse species' ethnomedicinal use in the various states.

Chemical Constituents

Ficus species are known to have a wide range of therapeutic uses because of their abundance of phytochemicals. Several scientists have been interested in *Ficus* species because of their advantageous qualities for human health. Many kinds of high-value chemicals, including flavonoids, glycosides, steroids, saponins, terpenes, tannins, coumarins, phenolic acids, alkaloids, and volatile compounds, are abundant in *Ficus* leaves, fruits, stem bark, roots, and latex. *Ficus* species possess a variety of biological actions, including antihypertensive, hypoglycemic, neuroprotective, antioxidant, analgesic, and anti-inflammatory properties, because of their abundance in phytochemical bioactive metabolites. The genus *Ficus* is a valuable source of bioactive phytochemicals that have health advantages for pharmaceutical formulation (Elish et al., 2023).

In the 1940s, researchers conducted the first scientific studies on the potential of fig latex to prevent cancer (Ullman et al., 1945, 1952; Ullman, 1952). A combination of 6-O-acyl- β -D-glucosyl- β -sitosterol isoforms from the latex of *F. carica* were isolated and their structures were clarified because of this study, and they showed anti-proliferative action in a number of tumor cell lines (Rubnov et al., 2001). *Ficus* species include some of the most promising cytotoxic chemicals, such as phenanthroindolizidine alkaloids and a group of triterpenoids containing C-28 carboxylic acid functional groups. Thus, three human cancer cell lines, including HONE-1 nasopharyngeal carcinoma cells, KB oral epidermoid carcinoma cells, and HT29 colorectal carcinoma cells, showed cytotoxicity in response to triterpenoids such as acetylbetulonic acid, acetylursolic acid, betulonic acid, 3-oxofriedelan-28-oic acid, ursolic acid, and ursonic acid isolated from the aerial roots of *F. microcarpa* (Chiang et al., 2005).

A total of 120 compounds that have been identified in different parts of the *Ficus* species are well documented in the review of Lansky et al. (2008). The alkaloids like 10S,13aR-antofine N-oxide, dehydrotylophorine, 2-demethoxytylophorine, 4,6-bis-(4-methoxyphenyl)-1,2,3-trihydroindolizidinium chloride, ficuseptine A, 14 α -hydroxyisotylocrebrine N-oxide, and tylophorine have been isolated from the leaves of *F. septica* while the isotylocrebrine and tylocrebrine have been isolated from the leaves and stems of the same species.

Other alkaloids like ficuseptine B, ficuseptine C, ficuseptine D, 10S,13aR-isotylocrebrine N-oxide, 10S,13aS-isotylocrebrine N-oxide, 10R,13aR-tylocrebrine N-oxide, 10S,13aR-tylocrebrine N-oxide, 10R,13aR-tylophorine N-oxide, 10S,13aR-tylophorine N-oxide isolated from the stems of *F. septica* and the 6-O-methyltylophorinidine has been isolated from the stem of *F. hispida* (Venkatachalam and Mulchandani, 1982). The various coumarins like bergapten, 4',5'-dihydropsoresalen, marmesin, and umbelliferone have been isolated from the leaves of *F. carica*. A coumarin i.e., psoralen is isolated from the leaves and roots of the *F. hirta* and *F. carica*.

The flavonoids are another important class of phytochemicals which are present in all the species. Genistin and kaempferitrin isolated from the leaves of the *F. septica* while the other flavonoids like isoquercitrin are isolated from leaves of *F. ruficaulis*. Rutin is isolated from the leaves of *F. carica* and *F. ruficaulis* (el-Kholy and Shaban, 1966; Chang et al., 2005). Some flavonoids like carpachromene, isoglabranin, norartocarpanone, norartocarpetin are isolated from the stems of *F. formosana*. The apigenin (flavonoid) isolated from the stems and roots of the *F. hirta* and *F. formosana*. Similarly, several flavonoids like alpinumisoflavone, cajanin, derrone, 5,7-dihydroxy-4-methoxy-3'-(2,3-dihydroxy-3-methylbutyl)isoflavone, ercibenin A, ercibenin C, genistein, 3'-(3-methylbut-2-enyl)biochanin A, and 5,7,2'-trihydroxy-4'-methoxyisoflavone are isolated from the stem bark of the *F. nymphaeifolia*. Hesperidin, 5-hydroxy-4',6,7,8-tetramethoxyflavone, and

4',5,6,7,8-pentamethoxyflavone have been isolated from the roots of the *F. hirta*. Fruits are an important part of the *Ficus* species that have anthocyanin like cyanidin-3-O-glucoside and cyanidin-3-O-rhamnoglucoside which have been isolated from the *F. carica* (Solomon et al., 2006). A lectin *Ficus benghalensis* agglutinin (FBA) was also identified in the seeds of the *F. benghalensis* (Singha et al., 2007). Some compounds like 6-O-linoleyl- β -D-glucosyl- β -sitosterol, 6-O-oleyl- β -D-glucosyl- β -sitosterol, 6-O-palmitoyl- β -D-glucosyl- β -sitosterol, and 6-O-stearyl- β -D-glucosyl- β -sitosterol have been also identified from the latex of the *F. carica* (Rubnov et al., 2001). Along with these several phenolic compounds, sterols, and triterpenoids have also been identified from the various parts of the *Ficus* species (Lansky et al., 2008).

In a recent review of Olaoluwa et al. (2022), a total of 118 phytochemicals from the various parts of the African *Ficus* species have been well documented. Singh and Sharma (2023) elaborated the Indian *Ficus* species for their phytochemical constituents. India has a total of 97 *Ficus* species, among them 25 species i.e., *F. auriculata*, *F. bengalensis*, *F. benjamina*, *F. carica*, *F. curtipes*, *F. deltoidea*, *F. elastica*, *F. erecta*, *F. exasperata*, *F. fistulosa*, *F. geniculata*, *F. hirta*, *F. hispida*, *F. lacor*, *F. lyrata*, *F. macrocarpa*, *F. mollis*, *F. palmata*, *F. pumila*, *F. racemosa*, *F. religiosa*, *F. retusa*, *F. sarmentosa*, *F. semicordata*, and *F. tikoua* have been evaluated and several phenylpropanoids, isoflavonoids, flavonoids, phenolic glycosides, monoterpenes, sesquiterpenes, triterpenes,

and alkaloids have been isolated and identified from these species while the remaining 72 species i.e., *F. abelii*, *F. filicauda*, *F. ischnopoda*, *F. nigrescens*, *F. fulva*, *F. langkokensis*, *F. pubigera*, *F. laevis*, *F. diversiformis*, *F. chartacea*, *F. laevis* var. *macrocarpa*, *F. crininervia*, *F. villosa*, *F. sagittata*, *F. recurva*, *F. pendens*, *F. hedaracea*, *F. punctata*, *F. ampelas*, *F. andamanica*, *F. assamica*, *F. copiosa*, *F. cyrtophylla*, *F. heterophylla*, *F. praetermissa*, *F. montana*, *F. subincisa*, *F. subincisa* var. *paucidentata*, *F. heteropleura*, *F. obscura* var. *borneensis*, *F. sinuata*, *F. subulata*, *F. guttata*, *F. variegata*, *F. prostrata*, *F. squamosa*, *F. ribes*, *F. magnoliifolia*, *F. nervosa*, *F. albipila*, *F. callosa*, *F. capillipes*, *F. alongensis*, *F. amplissima*, *F. arnottiana*, *F. caulocarpa*, *F. concinna*, *F. cupulata*, *F. hookeriana*, *F. maclellandii* var. *rhododendrifolia*, *F. rigida*, *F. rumphii*, *F. superba*, *F. tsjahela*, *F. virens*, *F. altissima*, *F. beddomei*, *F. costata*, *F. dalhousiae*, *F. drupacea*, *F. fergusonii*, *F. maclellandii*, *F. pellucidopunctata*, *F. stricta*, *F. sundaica*, *F. trimenii*, *F. gasparriniana*, *F. macrophylla*, *F. lamponga*, *F. neriifolia*, *F. talbotii*, and *F. tinctoria* have not been evaluated for the presence of phytoconstituents (Singh and Sharma, 2023).

Species

Genus *Ficus* is known to contain a total of 884 taxonomically accepted species (POWO 2023) that are as-

1. *F. abelii* Miq in Ann. Mus. Bot. Lugduno-Batavi 3: 281 (1867)
2. *F. abscondita* C.C.Berg in Adansonia, n.s., 20: 264 (1980)

3. *F. abutilifolia* (Miq.) Miq in Ann. Mus. Bot. Lugduno-Batavi 3: 288 (1867)
4. *F. acamptophylla* (Miq.) Miq in Ann. Mus. Bot. Lugduno-Batavi 3: 264 (1867)
5. *F. aculeata* A.Cunn. ex Miq in London J. Bot. 7: 426 (1848)
6. *F. adelpha* K.Schum. & Lauterb in Fl. Schutzgeb. Südsee: 284 (1900)
7. *F. adenosperma* Miq in Ann. Mus. Bot. Lugduno-Batavi 3: 233 (1867)
8. *F. adhatodifolia* Schot in K.P.J.Sprengel, Syst. Veg. 4(App.): 409 (1827)
9. *F. adolphi-friderici* Mildbr in G.W.J.Mildbraed (ed.), Wiss. Erg. Deut. Zentr.-Afr. Exped., Bot. 2: 185 (1911)
10. *F. aequatorialis* Dugand in Caldasia 1(4): 28 (1942)
11. *F. albert-smithii* Standl in Lloydia 2: 174 (1939)
12. *F. albipila* (Miq.) King in Ann. Roy. Bot. Gard. (Calcutta) 1: 179 (1888)
13. *F. albomaculata* C.C.Berg in Blumea 49: 165 (2004)
14. *F. allutacea* Blume in Bijdr. Fl. Ned. Ind.: 457 (1825)
15. *F. alongensis* Gagnep in Notul. Syst. (Paris) 4: 84 (1927)
16. *F. altissima* Blume in Bijdr. Fl. Ned. Ind.: 455 (1825)
17. *F. amadiensis* De Wild in Repert. Spec. Nov. Regni Veg. 12: 200 (1913)
18. *F. amazonica* (Miq.) André in Pl. Feuill. Ornem.: 164 (1866)
19. *F. americana* Aubl in Hist. Pl. Guiane 2: 952 (1775), nom. cons.
20. *F. ampana* C.C.Berg in Bull. Mus. Natl. Hist. Nat., B, Adansonia 8: 33 (1986)
21. *F. ampelos* Burm.f in Fl. Indica: 226 (1768)
22. *F. amplissima* Sm in A.Rees, Cycl. 14: n.º 1 (1810)
23. *F. amplocarpa* Govind. & Masil in Proc. Indian Acad. Sci., Pl. Sci. 91: 117 (1982)
24. *F. ampulliformis* Corner in Gard. Bull. Singapore 19: 387 (1962)
25. *F. anamalayana* Sudhakar & G.V.S.Murthy in Rheedeia 25: 1 (2015)
26. *F. anastomosans* Wall. ex Kurz in Forest Fl. Burma 2: 455 (1877)
27. *F. andamanica* Corner in Gard. Bull. Singapore 17: 454 (1960)
28. *F. androchaete* Corner in Gard. Bull. Singapore 17: 438 (1960)
29. *F. annulata* Blume in Bijdr. Fl. Ned. Ind.: 448 (1825)
30. *F. anserina* (Corner) C.C.Berg in Thai Forest Bull., Bot. 35: 5 (2007)
31. *F. antandronarum* (H.Perrier) C.C.Berg in Bull. Mus. Natl. Hist. Nat., B, Adansonia 8: 45 (1986)
32. *F. apiocarpa* (Miq.) Miq in Ann. Mus. Bot. Lugduno-Batavi 3: 289 (1867)
33. *F. apollinaris* Dugand in Caldasia 1(4): 31 (1942)
34. *F. araneosa* King in Ann. Roy. Bot. Gard. (Calcutta) 1: 136 (1888)
35. *F. arawaensis* Corner in Gard. Bull. Singapore 18: 89 (1961)
36. *F. arbuscula* K.Schum. & Lauterb in Fl.

- Schutzgeb. Südsee: 272 (1900)
37. *F. archboldiana* Summerh in J. Arnold Arbor. 22: 84 (1941)
 38. *F. archeri* Standl in Publ. Field Mus. Nat. Hist., Bot. Ser. 17: 167 (1937)
 39. *F. ardisioides* Warb in Bot. Jahrb. Syst. 20: 171 (1894)
 40. *F. arfakensis* King in J. Asiat. Soc. Bengal, Pt. 2, Nat. Hist. 56: 63 (1887)
 41. *F. aripuanensis* C.C.Berg & Kooy in Acta Amazonica 14(1-2 Suppl.): 195 (1984 publ. 1986)
 42. *F. armitii* King in J. Asiat. Soc. Bengal, Pt. 2, Nat. Hist. 55: 404 (1887)
 43. *F. arnottiana* (Miq.) Miq in Ann. Mus. Bot. Lugduno-Batavi 3: 287 (1867)
 44. *F. aspera* G.Forst in Pl. Esc.: 36 (1786)
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748. *F. stricta* Miq in Ann. Mus. Bot. Lugduno-Batavi 3: 266 (1867)
749. *F. stuhlmannii* Warb in Bot. Jahrb. Syst. 20: 161 (1894)
750. *F. subcaudata* C.C.Berg in Blumea 48: 298 (2003)
751. *F. subcongesta* Corner in Gard. Bull. Singapore 18: 93 (1961)
752. *F. subcordata* Blume in Bijdr. Fl. Ned. Ind.: 440 (1825)
753. *F. subcostata* De Wild in Repert. Spec. Nov. Regni Veg. 12: 197 (1913)
754. *F. subcuneata* Miq in Ann. Mus. Bot. Lugduno-Batavi 3: 235 (1867)
755. *F. subfulva* Corner in Gard. Bull. Singapore 17: 432 (1960)
756. *F. subgelderii* Corner in Gard. Bull. Singapore 17: 386 (1960)
757. *F. subglabritepala* C.C.Berg in Blumea 48: 543 (2003)
758. *F. subincisa* Buch.-Ham. ex Sm in Cycl. 14: n.º 91 (1810)
759. *F. sublimbata* Corner in Gard. Bull. Singapore 18: 50 (1960)
760. *F. submontana* C.C.Berg in Blumea 48: 563 (2003)
761. *F. subnervosa* Corner in Gard. Bull. Singapore 17: 411 (1960)
762. *F. subpisocarpa* Gagnep in Notul. Syst. (Paris) 4: 95 (1927)
763. *F. subpuberula* Corner in Gard. Bull. Singapore 17: 403 (1960)
764. *F. subsagittifolia* Mildbr. ex C.C.Berg in Adansonia, n.s., 20: 268 (1980)
765. *F. subsidens* Corner in Gard. Bull. Singapore 17: 454 (1960)
766. *F. subterranea* Corner in Gard. Bull. Singapore 18: 61 (1960)
767. *F. subtrinervia* K.Schum. & Lauterb in Fl. Schutzgeb. Südsee: 271 (1900)
768. *F. subulata* Blume in Bijdr. Fl. Ned. Ind.: 460 (1825)
769. *F. suffruticosa* Corner in Philos. Trans., Ser. B 256(808): 348 (1969)
770. *F. sulawesiana* C.C.Berg & Culmsee in Blumea 56: 267 (2011)

771. *F. sulcata* Elmer in Leafl. Philipp. Bot. 4: 1377 (1912)
772. *F. sumacoana* C.C.Berg in Blumea 52: 589 (2007)
773. *F. sumatrana* (Miq.) Miq in Ann. Mus. Bot. Lugduno-Batavi 3: 287 (1867)
774. *F. sundaica* Blume in Bijdr. Fl. Ned. Ind.: 450 (1825)
775. *F. superba* Miq in Ann. Mus. Bot. Lugduno-Batavi 2: 200 (1866)
776. *F. supfiana* Schltr in Bot. Jahrb. Syst. 67: 227 (1935)
777. *F. supperforata* Corner in Gard. Bull. Singapore 18: 16 (1960)
778. *F. sur* Forssk in Fl. Aegypt.-Arab. : 180 (1775)
779. *F. sycomorus* L in Sp. Pl.: 1059 (1753)
780. *F. talbotii* King in Ann. Roy. Bot. Gard. [Calcutta] 1: 51 (1887)
781. *F. tamayoana* Cuv.-Fig. & Carvajal in Albertoa 35: 270 (2008)
782. *F. tannoensis* Hayata in Icon. Pl. Formosan. 7: 36 (1918)
783. *F. tanypoda* Corner in Philos. Trans., Ser. B 253(783): 145 (1967)
784. *F. tarennifolia* Corner in Gard. Bull. Singapore 18: 62 (1960)
785. *F. temburongensis* C.C.Berg in Blumea 57: 151 (2012)
786. *F. tenuicuspadata* Corner in Gard. Bull. Singapore 17: 464 (1960)
787. *F. tepuiensis* C.C.Berg in Ernstia 6: 8 (1981)
788. *F. tequendamae* Dugand in Caldasia 1(4): 67 (1942)
789. *F. ternatana* Miq in Ann. Mus. Bot. Lugduno-Batavi 3: 296 (1867)
790. *F. tessellata* Warb in Bot. Jahrb. Syst. 20: 156 (1894)
791. *F. tettensis* Hutch in Bull. Misc. Inform. Kew 1915: 341 (1915)
792. *F. thailandica* C.C.Berg & S.Gardner in Thai Forest Bull., Bot. 35: 31 (2007)
793. *F. theophrastoides* Seem in Fl. Vit.: 252 (1868)
794. *F. thonningii* Blume in Rumphia 2: 18 (1838)
795. *F. ti-koua* Bureau in J. Bot. (Morot) 2: 213 (1888)
796. *F. tiliifolia* Baker in J. Linn. Soc., Bot. 21: 443 (1885)
797. *F. tinctoria* G.Forst in Fl. Ins. Austr.: 76 (1786)
798. *F. tonduzii* Standl in Contr. U.S. Natl. Herb. 20: 8 (1917)
799. *F. tonsa* Miq in Ann. Mus. Bot. Lugduno-Batavi 3: 235 (1867)
800. *F. torrentium* H.Perrier in Arch. Bot. Bull. Mens. 2: 150 (1928)
801. *F. torresiana* Standl in Publ. Field Columb. Mus., Bot. Ser. 18: 387 (1937)
802. *F. towarensis* Pittier in Bol. Soc. Venez. Ci. Nat. 4(30): 57 (1937)
803. *F. trachelosyce* Dugand in Caldasia 1(4): 69 (1942)
804. *F. trachypison* K.Schum in Fl. Schutzgeb. Südsee: 280 (1900)
805. *F. trachycoma* Miq in Syst. Verz. Ind.

- Archip. 2: 92 (1854)
806. *F. trapezicola* Dugand in *Caldasia* 7: 244 (1955)
807. *F. travancorica* King in *Ann. Roy. Bot. Gard. (Calcutta)* 1: 28 (1887)
808. *F. tremula* Warb in *Bot. Jahrb. Syst.* 20: 171 (1894)
809. *F. treubii* King in *Ann. Roy. Bot. Gard. (Calcutta)* 1: 105 (1888)
810. *F. trianae* Dugand in *Caldasia* 1(4): 70 (1942)
811. *F. trichocarpa* Blume in *Bijdr. Fl. Ned. Ind.*: 448 (1825)
812. *F. trichocerasa* Diels in *Bot. Jahrb. Syst.* 67: 188 (1935)
813. *F. trichoclada* Baker in *J. Linn. Soc., Bot.* 22: 524 (1887)
814. *F. trichopoda* Baker in *J. Linn. Soc., Bot.* 20: 261 (1883)
815. *F. tricolor* Miq in *Pl. Jungh.*: 53 (1851)
816. *F. trigona* L.f in *Suppl. Pl.*: 441 (1782)
817. *F. trigonata* L in *Pl. Surin.*: 17 (1775)
818. *F. triloba* Buch.-Ham. ex Voigt in *Hort. Suburb. Calcutt.*: 284 (1845)
819. *F. trimenii* King ex Trimen in *J. Bot.* 23: 242 (1885)
820. *F. triradiata* Corner in *Gard. Bull. Singapore* 17: 401 (1960)
821. *F. tristaniifolia* Corner in *Gard. Bull. Singapore* 17: 397 (1960)
822. *F. trivia* Corner in *Gard. Bull. Singapore* 17: 427 (1960)
823. *F. tsiangii* Merr. ex Corner in *Gard. Bull. Singapore* 18: 25 (1960)
824. *F. tsjakela* Burm.f. in *Fl. Indica*: 227 (1768)
825. *F. tsjahela* Burm.f. in *Fl. Ind.* 227
826. *F. tubulosa* Pelissari & Romaniuc in *Phytotaxa* 170: 208 (2014)
827. *F. tulipifera* Corner in *Gard. Bull. Straits Settlement.* 10: 150 (1939)
828. *F. tunicata* Corner in *Gard. Bull. Singapore* 18: 51 (1960)
829. *F. tuphapiensis* Drake in *J. Bot. (Morot)* 10: 211 (1896)
830. *F. turrialbana* W.C.Burger in *Phytologia* 26: 429 (1973)
831. *F. ulmifolia* Lam in *Encycl.* 2: 499 (1788)
832. *F. umbellata* Vahl in *Enum. Pl.* 2: 182 (1805)
833. *F. umbonata* Reinw. ex Blume in *Bijdr. Fl. Ned. Ind.*: 454 (1825)
834. *F. uncinata* (King) Becc in *For. Borneo*: 527 (1902)
835. *F. uniauriculata* Warb in *Bot. Jahrb. Syst.* 25: 616 (1898)
836. *F. uniglandulosa* Wall. & Miq in *London J. Bot.* 7: 431, descr. 1848
837. *F. urnigera* Miq in *Syst. Verz. Ind. Archip.* 2: 98 (1854)
838. *F. ursina* Standl in *Publ. Field Columb. Mus., Bot. Ser.* 17: 178 (1937)
839. *F. usambarensis* Warb in *Bot. Jahrb. Syst.* 20: 159 (1894)
840. *F. vaccinioides* Hemsl. & King ex King in *Ann. Roy. Bot. Gard. (Calcutta)* 1: 126 (1888)
841. *F. valaria* C.C.Berg in *Blumea* 52: 591 (2007)

842. *F. vallis-caucae* Dugand in *Caldasia* 2: 79 (1943)
843. *F. vallis-choudae* Delile in *Ann. Sci. Nat., Bot.*, sér. 2, 20: 94 (1843)
844. *F. variegata* Blume in *Bijdr. Fl. Ned. Ind.*: 459 (1825)
845. *F. variifolia* Warb in *Ann. Mus. Congo Belge, Bot.*, sér. 6, 1: 30 (1904)
846. *F. variolosa* Lindl. ex Benth in *London J. Bot.* 1: 492 (1842)
847. *F. vasculosa* Wall. & Miq in *London J. Bot.* 7: 454 (1848)
848. *F. vasta* Forssk in *Fl. Aegypt.-Arab.* : 179 (1775)
849. *F. velutina* Humb. & Bonpl. ex Willd in *Sp. Pl.*, ed. 4, 4: 1141 (1806)
850. *F. venezuelensis* C.C.Berg in *Fl. Venezuela , Morac.-Cecropiac.*: 186 (2000)
851. *F. vermifuga* Miq in *Ann. Mus. Bot. Lugduno-Batavi* 3: 300 (1867)
852. *F. verruculosa* Warb in *Bot. Jahrb. Syst.* 20: 166 (1894)
853. *F. versicolor* Bureau in *Ann. Sci. Nat., Bot.*, sér. 5, 14: 256 (1872)
854. *F. verticillaris* Corner in *Gard. Bull. Singapore* 18: 27 (1960)
855. *F. vieillardiana* Bureau in *Ann. Sci. Nat., Bot.*, sér. 5, 14: 258 (1872)
856. *F. villosa* Blume in *Catalogus*: 37 (1823)
857. *F. virens* Aiton in *Hort. Kew.* 3: 451 (1789)
858. *F. virescens* Corner in *Gard. Bull. Singapore* 19: 398 (1962)
859. *F. virgata* Reinw. ex Blume in *Bijdr. Fl. Ned. Ind.*: 454 (1825)
860. *F. vitiensis* Seem in *Fl. Vit.*: 250 (1868)
861. *F. vittata* Vázq.Avila in *Acta Amazonica* 14(1-2 Suppl.): 211 (1984 publ. 1986)
862. *F. vogeliana* Miq in *Ann. Mus. Bot. Lugduno-Batavi* 3: 295 (1867)
863. *F. voponensis* Desv in *Ann. Sci. Nat., Bot. Ser. 2*, 18: 310 1842
864. *F. vrieseana* Miq in *Ann. Mus. Bot. Lugduno-Batavi* 3: 234 (1867)
865. *F. wakefieldii* Hutch in *Bull. Misc. Inform. Kew* 1915: 335 (1915)
866. *F. wamanguana* Weiblen & Whitfeld in *Harvard Pap. Bot.* 15: 7 (2010)
867. *F. warburgii* Elmer in *Leaf. Philipp. Bot.* 1: 247 (1907)
868. *F. wassa* Roxb in *Fl. Ind. ed.* 1832, 3: 539 (1832)
869. *F. watkinsiana* F.M.Bailey in *Bot. Bull. Dept. Agric. Queensland* 2: 18 (1891)
870. *F. webbiana* Miq in *Ann. Mus. Bot. Lugduno-Batavi* 3: 297 (1867)
871. *F. wildemaniana* Warb. ex De Wild. & T.Durand in *Ann. Mus. Congo Belge, Bot.* , sér. 3, 1: 217 (1901)
872. *F. xylophylla* Wall. ex Miq in *Ann. Mus. Bot. Lugduno-Batavi* 3: 286 (1867)
873. *F. yoponensis* Desv in *Ann. Sci. Nat., Bot.*, sér. 2, 18: 310 (1842)
874. *F. ypsilophlebia* Dugand in *Caldasia* 1(4): 73 (1942)
875. *F. yunnanensis* S.S.Chang in *Acta Phytotax. Sin.* 22: 69 (1984)
876. *F. zuliensis* C.C.Berg & Simonis in *Ernstia* 6: 10 (1981)

Ficus racemosa L.

F. racemosa is a member of the Moraceae family, which is native to North Queensland, Pakistan, and other parts of the tropical biome that experiences seasonal dryness (POWO, 2023). It goes under several names, including 'Umbar', 'Udumbara', 'Gular' fig, and Cluster fig. Its elliptic or ovate, dark green leaves are often found along streams, in evergreen and deciduous forests at elevations up to 1800 metres (Paarakh, 2009; Sharma et al., 2023). It belongs to the group of four sacred trees known as "Nalpamara" or "Ksirivrkas," which means that homes and temples should have them planted (Paarakh, 2009). Bark, leaves, and unripe fruit, all have carminative, astringent, stomachic, and vermicide qualities (Joseph and Raj, 2010). It has been widely utilized in India's traditional medical system, which emphasizes on all its therapeutic applications, to treat inflammatory diseases, jaundice, dysentery, diabetes, diarrhea, and biliary issues (Cherian and Augusti, 1995).

The leaves are useful for treating bronchitis and are considered astringent in the Unani medical system (Keshari et al., 2016). The leaves are used as a mouthwash for spongy gums and to cure bilious infections and diarrhea (Shikshartha and Mittal, 2011). To lighten the complexion, a paste made from the delicate leaf buds is applied to the skin. As an aphrodisiac, latex (milky juice) is used to treat hemorrhoids, boils, traumatic swelling, adenitis, parotitis, orchitis, toothaches, vaginal diseases, and diarrhea, especially in youngsters (Kosankar and Aher, 2018). On

persistently infected wounds, latex is used externally to reduce discomfort and edema and to encourage healing (Varandani et al., 2019). To propagate the plant, cut off the stem and root suckers (Ahmed and Urooj, 2010).

Classification

Kingdom	-	Plantae
Subkingdom	-	Tracheobionta
Division	-	Magnoliophyta
Superdivision	-	Spermatophyta
Class	-	Magnoliopsida, Equisetopsida
Subclass	-	Hamamelididae
Order	-	Rosales, Urticales
Family	-	Moraceae
Genus	-	<i>Ficus</i>
Species	-	<i>racemosa</i>

Common Names

Cluster Fig, Country Fig, Gular fig, Jagya-dimoru, Mou-dimoru, Udumbara, Goolar, Jantu Phal, Dumar, Pushp-hina, Udumbar, Dumrii, Udumbara, Audumbara, Krmiphalah, Shitavalkah, Saumya.

Global Distribution

The *F. racemosa* is globally distributed from Pakistan to North Queensland in the tropical

biome (POWO, 2023). It is also found in Burma, China, Indonesia, Malaysia, and Australia (Sharma et al., 2023). According to the Plants of the World Online database (POWO, 2023), it is native to Andaman Is., Assam, Bangladesh, Borneo, Cambodia, China South-Central,

China Southeast, East Himalaya, India, Jawa, Laos, Lesser Sunda Is., Malaya, Myanmar, Nepal, New Guinea, Northern Territory, Pakistan, Queensland, Sri Lanka, Sulawesi, Sumatera, Thailand, Vietnam, West Himalaya, Western Australia (Fig. 2).

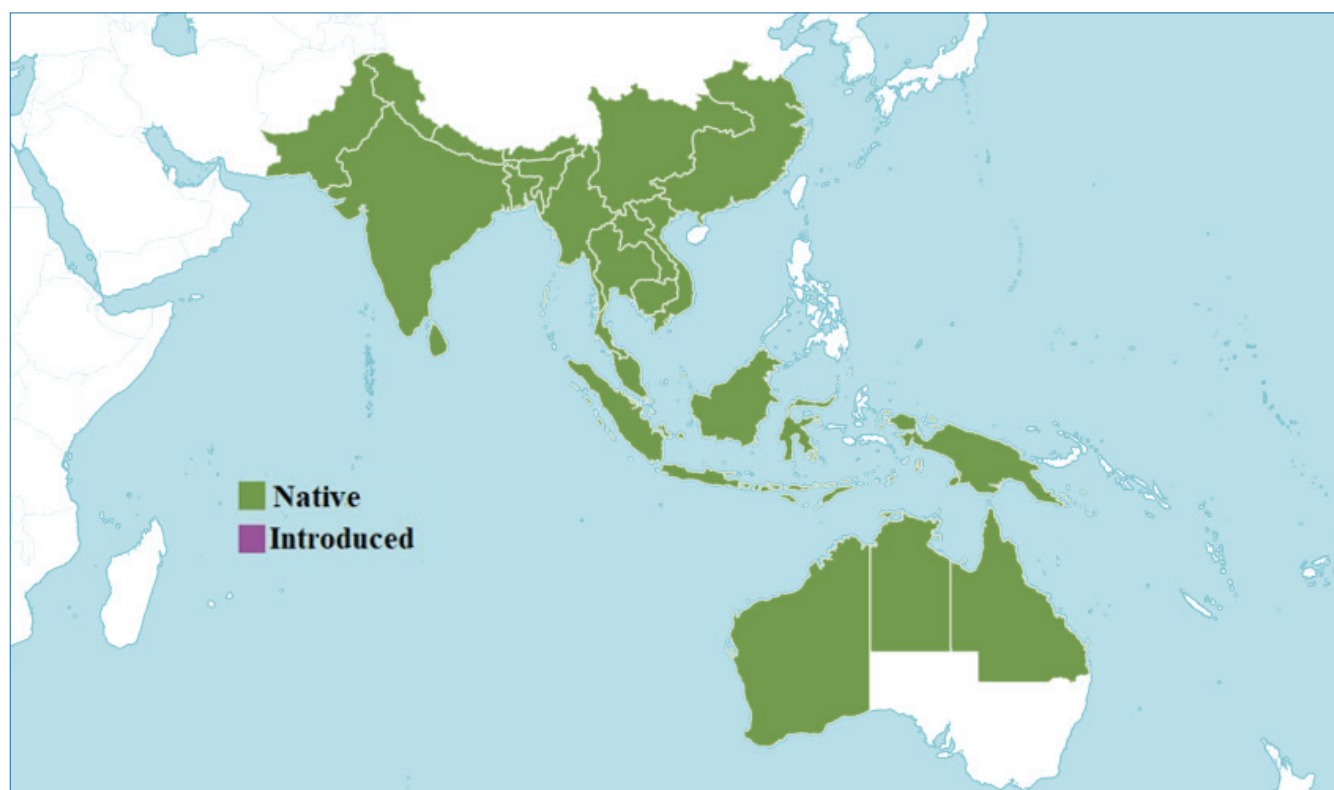


Fig. 2 Global distribution of genus *F. racemosa*

Distribution in India

It is a large deciduous tree which is cultivated as well as grows in wild and distributed all over India from Himalayan ranges, Punjab, Khasia mountain, Chota Nagpur, Bihar, Orissa, West Bengal, Rajasthan, Deccan and south India (Paarakh, 2009). In common, it is found throughout the India.

Ethnopharmacology and Traditional Uses

As a traditional herbal cure, *F. religiosa* is used alone or in combination with other herbs to treat a variety of health issues. It is a sacred plant in India. In the system of Ayurvedic medicine, it is taken as an herbal remedy to cure a variety of illnesses. It is possible to consume its parts uncooked, as capsules,

pills, ointments, or as oil. Every composition serves a different purpose and has therapeutic potential for a specific ailment. Drying and grinding it in conventional grinders allows it to be ingested even as a powder. For some illnesses including diabetes mellitus, urinary problems, etc., powder form is also quite beneficial. The powdered stem bark of *F. religiosa* is thought to work better when consumed with honey, either before or after a meal (Sandeep et al., 2018).

In a comparable way, there are other goods or combinations on the market that are intended to treat illnesses. When applied to the skin two to three times a day, a few drops of Nalpamaradi oil mixed with *F. religiosa* bark is particularly helpful for dermatitis, scabies, eczema, acne, urticaria, and pimples (Singh et al., 2018). When taken in doses of 1-3 gm with honey, Nyagrodhadi *churna*, an Ayurvedic remedy composed of the stem bark of *F. religiosa*, is highly beneficial for treating urinary problems and diabetes (Sandeep et al., 2018). When taken daily with an equivalent amount of water, Sarivadyasava, another Ayurvedic medication composed of *F. religiosa* bark, is beneficial for kidney and urinary problems (Sandeep et al., 2018). When applied with cotton for an hour to the problematic areas of the skin, Panchavalkadi tailam, an Ayurvedic skin care oil composed of the bark of *F. religiosa*, helps relieve eczema, dermatitis, herpes, and bleeding skin disorders (Sandeep et al., 2018).

In the conventional medical system, every component of this plant—leaves, fruits, seeds,

bark, latex, and root sap—has therapeutic value. Plant components have been used traditionally as fodder (Faiyaz et al., 2010). Bilious diseases are treated with a combination of leaves powdered with honey (Kirtikar and Basu, 1975; El Ghouizi et al., 2023). Hair is rubbed with leaf juice to keep it from splitting. Measles, boils, and blisters are treated using leaf latex (Siwakoti and Siwakoti, 2000). The fruit is a spleen styptic tonic, stomachic, astringent, and carminative that is used to treat dry cough, menorrhoea, hemoptysis, intestinal worms, voice loss, kidney diseases, and astringent blood disorders (Chopra et al., 1958; Dubey et al., 2018).

Fruits are used to treat constipation, diarrhea, and visceral blockage (Vihari, 1995). Leprosy is thought to be cured with a fruit and bark treatment (Lansky et al., 2008; Sharma et al., 2023). It is believed that the fruit can effectively treat diabetes (Nadkarni et al., 1976). Pectoris, diabetes, and skeletal problems are all treated with the seeds (Pahari et al., 2022; Sharma and al., 2023). Bark has an astringent quality. Bark tea is used as a mouthwash for conditions such as spongy gums, menorrhoea, hemoptysis, diabetes, leukorrhoea, gonorrhoea, urinary problems, and skin diseases. It is also very beneficial in situations when an abortion is about to occur (Chopra et al., 1958; Akbar and Akbar, 2020; Paramanya et al., 2023). It is also advised in urology, particularly effective in threatening abortions, and used as a wound wash. Bark decoction is used for piles and asthma (Kirtikar and Basu, 1975). It has been said that the sap taken from the trunk is a useful medication

for diabetes. Stem bark paste is used to treat wounds, edema, leukorrhea (Paudyal, 2000), dysentery, and diarrhea (Tiwari, 2001).

As an aphrodisiac, latex is used to treat vaginal diseases, traumatic swelling, diarrhea, dysentery, hemorrhoids, adenitis, parotitis, orchitis, and boils (Yadav, 1999; Patil et al., 2010). Additionally, it has been used topically to lessen swelling, irritation, and infection in chronically infected wounds and to accelerate healing (Gardia et al., 2021) as well as to treat stomachaches (Ghimire et al., 2000), cholera, and the mumps (Basnet, 1998). The root's sap is applied topically to treat mumps and other inflammatory glandular enlargements, as well as for gonorrhea and diabetes (Chopra et al., 1958). The traditional benefits of using roots include anti-inflammatory bone fracture, and wound healing activities (Mishra et al., 2023). Furthermore, they are administered against mumps, diabetes, pectoral problems, diarrhea, and other inflammatory glandular enlargements (Akbar and Akbar, 2020). It is said that root sap can treat bovine malaria, chronic wounds, and heat stroke (Thapa, 2001).

Pharmacologically it has been evaluated and it showed the antidiuretic (Kosankar and Aher, 2018), anti-carcinogenic (Ahmed et al., 2013; Bhanuse et al., 2022), hepatoprotective (Shinde et al., 2019; Suriyakalaa et al., 2022), anthelmintic (Chandrashekhar et al., 2008; Devanesan et al., 2018; Kapile et al., 2022), hypotensive (Singh et al., 2011), antifertility (Ahirwar et

al., 2011; Singh et al., 2018; Soni et al., 2018; Khosla et al., 2022), antifungal (Pingale et al., 2019; Nawaz et al., 2020), hypoglycemic (Abusufyan et al., 2018; Liu et al., 2022), anti-inflammatory (Shinde et al., 2023; Rastogi et al., 2018; Sharma et al., 2023), antioxidant (Yadav et al., 2019; Mirahmad et al., 2022; Bhatia et al., 2023), antiulcer (Mishra et al., 2023; Nasution et al., 2016; Pathak and Sharma, 2021), gastroprotective (Rao et al., 2008), antimicrobial (Veerapur et al., 2009), anti-obesity (Son and Dhiman, 2020), antipyretic (Kumar et al., 2019; Mishra et al., 2023), antitussive (Bhaskara Rao et al., 2003), antifilarial (Mishra et al., 2005), chemo-preventive (Khan and Sultana, 2005; Tayyib, 2023), wound healing (Bakoriya et al., 2015), hypolipidemic (Sophia and Manoharan, 2007; Kar et al., 2023), and analgesic activities (Malairajan et al., 2006; Shinde et al., 2023) along with the various toxicity studies also performed on this (Rao et al., 2002; Krishnaraju et al., 2006; Deshmukh et al., 2007; Bommakanti et al., 2023; Haque et al., 2023).

Selection of the Sites and Characteristics Studied

The distribution, morphological variations, and association of *F. racemosa* were investigated across the Ganga River. The Ganga began from the Gomukh in Gangotri glacier and ended at Gangasagar in the Bay of Bengal. A total of 26 sites were selected with two sites ranging between around 100 km in distance while the whole distance is about 2600 km

(Table 1). Plant diversity was assessed up to 10 km on both sides of each site. The plants were identified and deposited in the Patanjali Research Foundation Herbarium with an acronym of PRFH for future records. A bulk sample of the plant was taken from each site in a large polybag which was deposited in the analytical laboratory for phytochemical profiling.

Table 1 Different studied sites and their GPS coordinates along with *F. racemosa* status

Site	Locality	GPS Coordinates			Status
		Altitude (m)	Latitude (N)	Longitude (E)	
S1	Gomukh	4023	30.80	79.15	Absent
S2	Gangotri	3415	30.98	78.93	Absent
S3	Uttarkashi	1158	30.73	78.44	Absent
S4	Devprayag	830	30.15	78.60	Absent
S5	Haridwar	314	29.97	78.17	Present
S6	Bijnor	225	29.37	78.13	Absent
S7	Narora	174	28.20	78.38	Present
S8	Budaun	164	28.05	79.12	Absent
S9	Farrukhabad	151	27.37	79.63	Present
S10	Bithoor	126	26.61	80.27	Present
S11	Dalmau	115	26.07	81.03	Present
S12	Prayagraj	98	25.45	81.85	Present
S13	Mirzapur	80	25.15	82.58	Present
S14	Varanasi	81	25.32	83.01	Present
S15	Ballia	67	25.76	84.15	Present
S16	Revelganj	52	25.78	84.67	Present
S17	Patna	53	25.61	85.14	Absent
S18	Barh	47	25.48	85.72	Absent
S19	Bahachouki	55	25.30	86.36	Absent
S20	Farka	42	25.23	87.09	Present
S21	Sahebganj	16	25.25	87.65	Present
S22	Farakka Bar-rage	30	24.82	87.90	Absent
S23	Murshidabad	18	24.18	88.27	Absent
S24	Mayapur	11	23.43	88.39	Absent
S25	Hoogli	9	22.91	88.40	Absent
S26	Gangasagar	4	22.19	88.19	Present

Local Occurrence

The plant was recorded in all the sites, but it was collected for the analytical studies only from the sites 5, 7, 9, 10, 11, 12, 13, 14, 15, 16, 20, 21, and 26, due to these sites being the source of its bulk collection. For the remaining sites as 4, 6, 8, 17, 18, 19, 22, 23, 24, and 25, it was only representative; it was absent in site 1, 2, and 3. Hence, it may be concluded that these sites require more conservation of this species.

Taxonomic Treatment

F. racemosa L., Sp. PL: 1060. 1753; Comer, Gard. Bull. Singapore 21: 34. 1965; Khanna, Geophytology 47(1): 100. 2017. *F. glomerata* Roxb., Pl Coromandel 2: 13. t. 123. 1799; King in Hook.f., FL Bntl India 5: 535. 1888; Duthie, FL Gangetic Plain 3: 160. 1915; FL Uttar Pradesh 2: 476. 2020.

Synonyms

The Plants of the World Online database mentioned it with its 25 heterotypic synonyms (Powo, 2023) as:

Heterotypic Synonyms

1. *Covellia glomerata* (Roxb.) Miq. in London J. Bot. 7: 465 (1848)
2. *C. lanceolata* (Buch.-Ham. ex Roxb.) Miq. in London J. Bot. 7: 465 (1848)
3. *C. mollis* Miq. in London J. Bot. 7: 466 (1848)
4. *F. acidula* King in Ann. Roy. Bot. Gard. [Calcutta] 1: 176 (1888)
5. *F. chittagonga* Miq. in Ann. Mus. Bot. Lugduno-Batavi 3: 228 (1867)
6. *F. glomerata* Roxb. in Pl. Coromandel 2: 13 (1799)
7. *F. glomerata* var. *chittagonga* (Miq.) King in Ann. Roy. Bot. Gard. [Calcutta] 1: 174 (1888)
8. *F. glomerata* var. *elongata* King in Ann. Roy. Bot. Gard. [Calcutta] 1: 173 (1888)
9. *F. glomerata* var. *miquelii* King in Ann. Roy. Bot. Gard. [Calcutta] 1: 174 (1888)
10. *F. glomerata* var. *mollis* (Miq.) King in Ann. Roy. Bot. Gard. [Calcutta] 1: 174 (1888)
11. *F. gooleree* Roxb. in Fl. Ind., ed. 1832. 3: 538 (1832)
12. *F. henrici* King in Ann. Roy. Bot. Gard. [Calcutta] 1: 174 (1888)
13. *F. lanceolata* Buch.-Ham. ex Roxb. in Fl. Ind., ed. 1832. 3: 557 (1832)
14. *F. leucocarpa* (Miq.) Miq. in Ann. Mus. Bot. Lugduno-Batavi 3: 285 (1867)
15. *F. lucescens* Blume in Bijdr. Fl. Ned. Ind.: 444 (1825)
16. *F. mollis* (Miq.) Miq. in Ann. Mus. Bot. Lugduno-Batavi 3: 283 (1867), nom. illeg.
17. *F. racemosa* var. *elongata* (King) M.F.Barrett in Bull. Torrey Bot. Club 73: 323 (1946)
18. *F. racemosa* var. *miquelii* (King) Corner in Gard. Bull. Singapore 21: 35 (1965)
19. *F. racemosa* var. *mollis* (Miq.) M.F.Barrett in Bull. Torrey Bot. Club 73: 323 (1946)
20. *F. racemosa* var. *vesca* (F.Muell. ex Miq.) M.F.Barrett in Bull. Torrey Bot. Club 73: 323 (1946)

21. *F. semicostata* F.M.Bailey in Queensland Agric. J. 26: 316 (1911)
 22. *F. trichocarpa* f. *glabrescens* Engl. in Bot. Jahrb. Syst. 7: 452 (1886)
 23. *F. vesca* F.Muell. ex Miq. in J. Bot. Néerl. 1: 243 (1861)
 24. *Urostigma leucocarpum* Miq. in London J. Bot. 6: 576 (1847)
 25. *U. lucescens* (Blume) Miq. in Fl. Ned. Ind. 1(2): 341 (1859)
- Another database i.e., World Flora Online (WFO, 2023) mentioned it with a total of the following twenty-seven synonyms-
1. *Covellia glomerata* Miq in London J. Bot. 7: 465 (1848)
 2. *C. lanceolata* Miq in London J. Bot. 7: 465 (1848)
 3. *C. mollis* Miq in London J. Bot. 7: 466 (1848)
 4. *F. acidula* King in Ann. Roy. Bot. Gard. [Calcutta] 1: 176 (1888)
 5. *F. chittagonga* Miq in Ann. Mus. Bot. Lugduno-Batavi 3: 228 (1867)
 6. *F. glomerata* Blanco in Fl. Filip. 683 1837
 7. *F. glomerata* Roxb in Pl. Coromandel 2: 13 (1799)
 8. *F. glomerata* var. *chittagonga* (Miq.) King in Ann. Roy. Bot. Gard. [Calcutta] 1: 174 1888
 9. *F. glomerata* var. *elongata* King in Ann. Roy. Bot. Gard. [Calcutta] 1: 173 1888
 10. *F. glomerata* var. *miquelii* King in Ann. Roy. Bot. Gard. [Calcutta] 1: 174 1888
 11. *F. glomerata* var. *mollis* (Miq.) King in Ann. Roy. Bot. Gard. [Calcutta] 1: 174 1888
 12. *F. goolereea* Roxb in Fl. Ind. ed. 1832, 3: 538 (1832)
 13. *F. henrici* King in Ann. Roy. Bot. Gard. [Calcutta] 1: 174 (1888)
 14. *F. lanceolata* Buch.-Ham. ex Roxb in Fl. Ind. ed. 1832, 3: 557 (1832)
 15. *F. leucocarpa* Miq in Ann. Mus. Bot. Lugduno-Batavi 3: 285 (1867)
 16. *F. lucescens* Blume in Bijdr. Fl. Ned. Ind.: 444 (1825)
 17. *F. mollis* Miq in Ann. Mus. Bot. Lugduno-Batavi 3: 283. 1867
 18. *F. racemosa* var. *elongata* (King) M.F.Barrett in Bull. Torrey Bot. Club 73: 323 1946
 19. *F. racemosa* var. *miquelii* (King) Corner in Gard. Bull. Singapore 21: 35 1965
 20. *F. racemosa* var. *mollis* (Miq.) M.F.Barrett in Bull. Torrey Bot. Club 73: 323 1946
 21. *F. racemosa* var. *racemosa*
 22. *F. racemosa* var. *vesca* (Miq.) M.F.Barrett in Bull. Torrey Bot. Club 73: 323 (1946)
 23. *F. semicostata* F.M.Bailey in Queensland Agric. J. 26: 316 (1911)
 24. *F. trichocarpa* f. *glabrescens* Engl in Bot. Jahrb. Syst. 7: 452 1886
 25. *F. vesca* F.Muell. ex Miq in J. Bot. Néerl. 1: 243 (1861)
 26. *Urostigma leucocarpum* Miq in London J. Bot. 6: 576 (1847)
 27. *U. lucescens* Miq in Fl. Ned. Ind. 1(2): 341 (1859)

Botanical Description

Tree, 25-30m, evergreen, monoecious. Trunk with or without aerial roots, bark whitish, grayish, pinkish brown, smooth, young twigs with fine white pubescence, soon glabrous. Branchlets brown, young leaf blades, and figs with bent hairs or densely covered with soft white pubescence. Stipules 12-15 × 4-5 mm, membranous, acute-acuminate, brown, sub-persistent, ovate-lanceolate, pubescent. Leaves alternate, petiole 2-3 cm; lamina ovate-lanceolate, elliptic-obovate 5-20 × 2.5-12 cm, abaxially pale green, pubescent when young, glabrescent, leathery, or not, base oblique or not, cuneate to obtuse, margin entire, obtuse, or subacute to occasionally acuminate at apex,

glabrous on both sides; basal lateral nerves 2, secondary nerves 4-8 pairs. Cystoliths present. Figs in a tumor like aggregate on short branchlets of old stem, few to many, 1.5-2.5 cm in diameter, reddish orange when mature, pear-shaped, subpyriform-globose, basally attenuated into a stalk, closed by 5-6, pink-brown bracts without internal bristles, apical pore navel-like, flat. Male flowers sessile, ostiolar in 23-whorls; calyx 3-4, united, lobes dentate-lacerate, red; stamens 2, pistillode present. Female flowers: sessile or subsessile, sepals 3-4, united, linear, apex 3-4 toothed, ovary substipitate, style lateral, glabrous stigma simple, clavate. Gall flowers pedicellate, dispersed among females. Seeds lenticular, $2n=26$ (Fig. 3A, B).



Fig. 3 A Plant habit



Fig. 3 B (a) Plant twig (b) Female flower (c) Male flower (d) Gall flower (e) Bract (f) Stamen (g) Stipule (h) Hypanthodium (i) L.S of hypanthodium

Anatomical Features

Structure of Leaf

The leaves have two wings and a central midrib. They are dorsiventral. The epidermis is the outermost layer; it has lithocysts and a thin cuticle covering it. It has a convex midrib. Two layers of hypodermis are found

underneath the epidermis. Ten to fifteen layers of collenchymal tissue envelop the core vascular bundles. Both the adaxial and abaxial epidermal layers are covered by the bundle sheath. There are present annular xylem vessels. Adaxial palisade cells arranged in 1-3 layers make up the dorsiventral mesophyll. Multiple layers of aerenchymatous

parenchyma make up the spongy tissue. The crystals are prismatic and druse forms. The midrib parenchyma and bundle sheath are the primary locations for both crystals. Both the

adaxial and abaxial surfaces contain tannin cells. Laticiferous tubes that are not branched comprise the secretory element (Fig. 4).

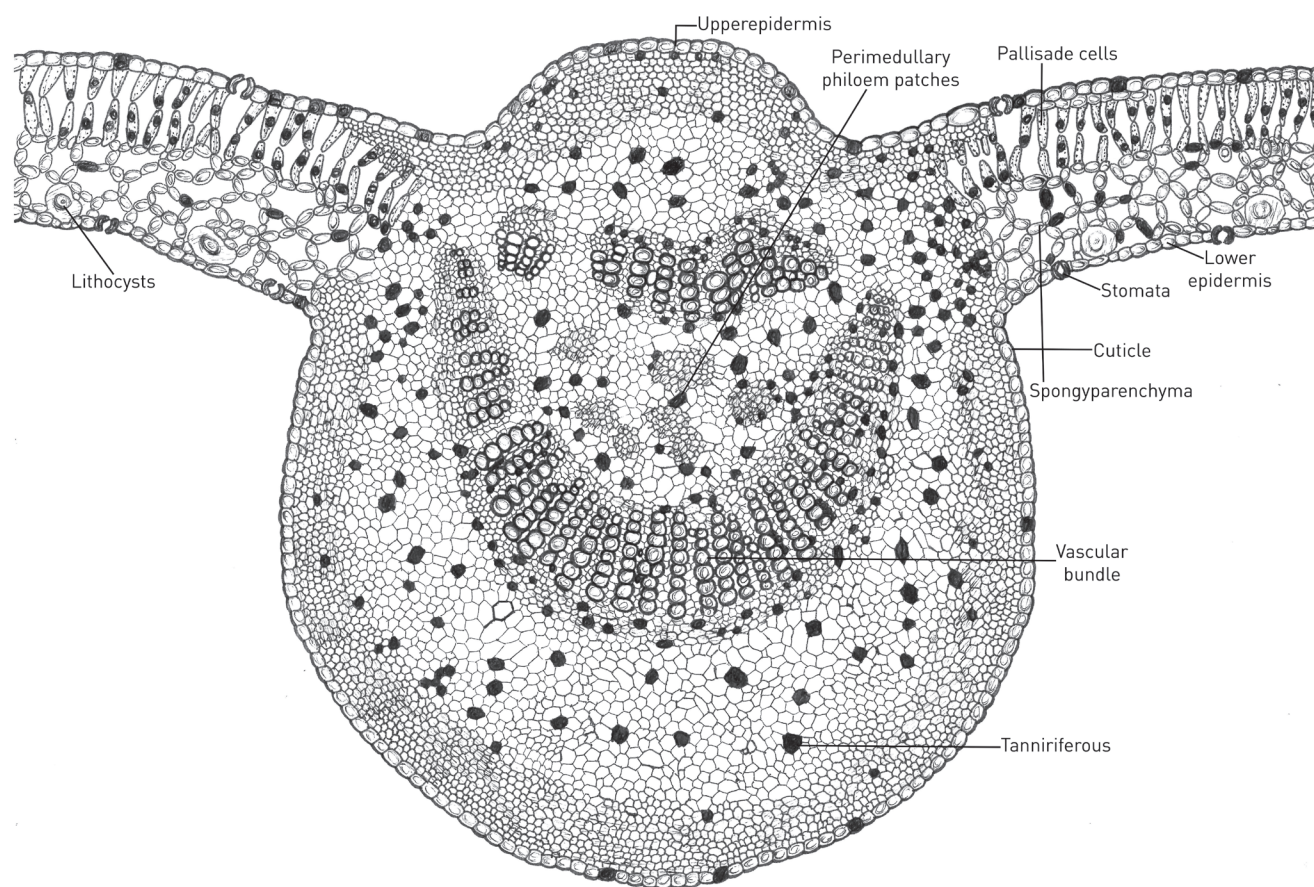


Fig. 4 TS of the leaf

Structure of Petiole

The petiole in TS is bean shaped. Epidermis is rectangular, squarish, and oval having cuticle and numerous nonglandular unicellular simple, trichomes. Below the epidermis, 7-8 layers of angular collenchymatous hypodermis is present. The collenchymatous cells are circular, oval, and polygonal cells. The ground tissue is composed of parenchymatous thin-

walled cells that are loosely arranged, circular, oval, and polygonal in shape. Vascular bundles are many, small, scattered in the centre. Each vascular bundle surrounded by 2-4 layers of sclerenchymatous cells. These cells are triangular or polygonal in shape and compactly arranged. The vascular bundles are conjoint, collateral and closed. Phloem 5-7 layered, composed of thin walled, compactly arranged circular, oval, triangular, and polygonal cells.

Xylem vessels are thick walled and arranged in 4-6 rows. Some perimedullary phloem

patches are present at centre. The laticifers are common in all the tissues (Fig. 5).

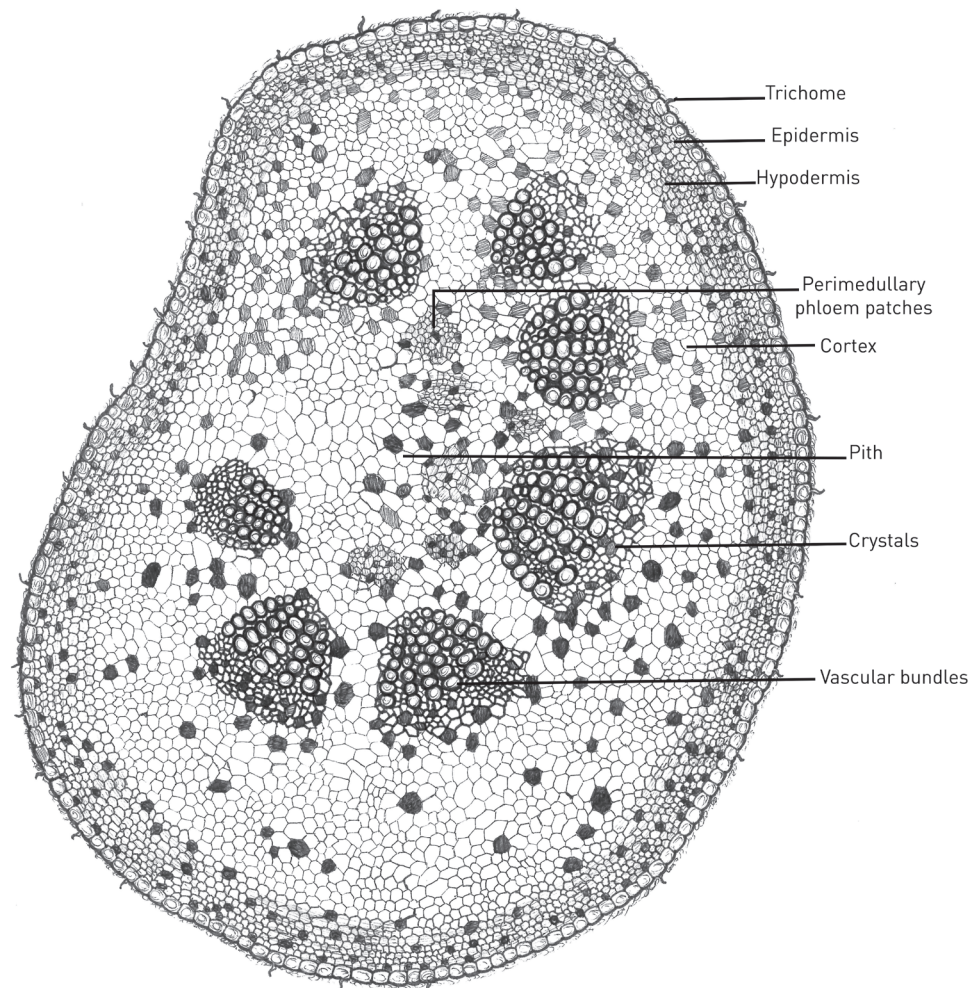


Fig. 5 TS of the petiole

Structure of Stem

TS of the stem comprise of bark. The periderm shows the outer phloem or cork which is consists of 2 layers of thickly suberised cells; middles phellogen or cork cambium is made up of a continuous layer of tangentially elongated and thin-walled cells; and inner phelloderm or secondary cortex made up of a few layers of parenchymatous cells, some

of the cells contained numerous chloroplasts, while a few others showed thick-walled fibres. Crystals of calcium oxalate and tannin were seen in the cortical cells. There are two types of crystals: prismatic and rhomboidal. Secondary phloem and secondary xylem are found on the inner side of the cortex. There is primary xylem and central pith visible next to the secondary xylem (Fig. 6).

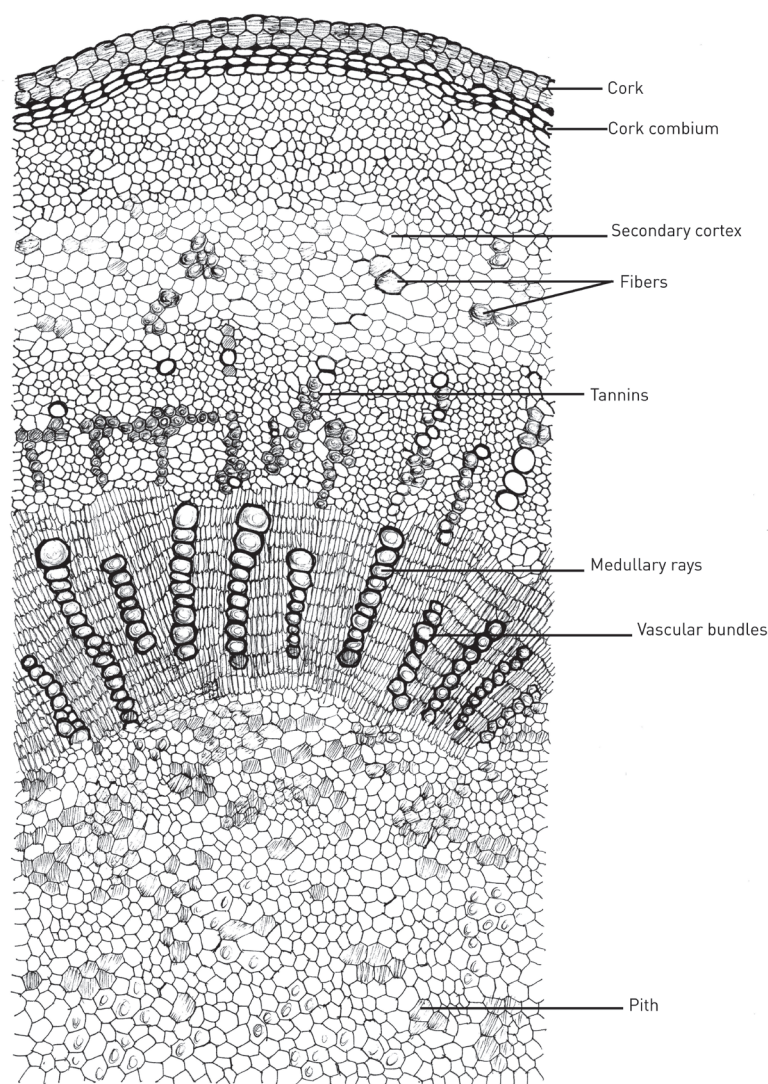


Fig. 6 TS of the stem

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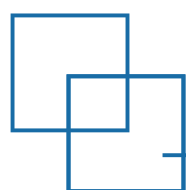
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CHAPTER 02

Bibliometric Analysis



INTRODUCTION

The *Ficus racemosa* L., belonging to the family Moraceae is a widely known plant found in various areas of Southeast Asia. This plant possesses numerous medicinal properties and is frequently utilized in wound healing (Khan et al., 2023). Various parts of the plant such as fruit, leaves, and bark, have therapeutic properties. These properties comprise antidiarrheal, anti-inflammatory, antipyretic, antifungal, antibacterial, hypolipidemic, antilarial, and hepatoprotective effects. Its fruit is used to treat various diseases such as leprosy, menorrhagia, leukorrhea, and blood disorders, as well as burns, intestinal worms, dry cough, and urinary tract infections (Yadav et al., 2015; Pahari et al., 2022). In Ayurveda, each part of this plant is esteemed for its medicinal benefits (Chaware et al., 2020). It has been widely utilized in treating biliary disorders, jaundice, dysentery, diabetes, diarrhea, and inflammation. The fruit, bark, roots, and latex of *F. racemosa* contain a plethora of phytochemicals, physicochemical compounds, and minerals, including calcium (Ca), potassium (K), magnesium (Mg), phosphorus (P), and iron (Fe). Trees have significant nutritional content within their fruit and bark, including crude protein, total lipids, crude fat, sugars, and starch (Kannan et al., 2024). The leaves of this plant are rich in reducing sugars, flavonoids, and minerals. These attributes render *F. racemosa* an interesting subject for researchers examining novel therapeutic agents and exploring various approaches to modern medicine.

Bibliometric analysis is a fundamental technique in modern scientific analysis, providing a comprehensive evaluation of the scholarly area encompassing a particular subject or topic (Pessin et al., 2022). The present study examines the research landscape of *F. racemosa* through bibliometric analysis, exploring the extensive literature, research trends, and knowledge dissemination associated with this versatile and widely studied plant species. The bibliometric analysis enables the investigation of both quantitative and qualitative extents within scholarly publications, providing researchers with the means to scrutinize patterns, trends, and the evolutionary trajectory of scientific literature related to *F. racemosa* (Goyal et al., 2021). This analytical approach involves examining publication metrics, citation patterns, author collaborations, geographical



distributions, and thematic emphases within the body of scientific literature (Vieira, 2022). Scientifically analyzing bibliographic data of *F. racemosa* provides researchers with a comprehensive understanding of the extent and scope of research conducted on this plant species.

The bibliometric analysis is considered a valuable tool to navigate and comprehend the dynamic research environment associated with this multifaceted plant species, providing researchers with meaningful insights to track knowledge progression and stimulate innovation in various related fields. The objective of this study was to conduct a comprehensive bibliometric analysis of scholarly literature dedicated to *F. racemosa* research, to gain insights into past research trends, identify significant contributors, understand citation patterns, and delineate collaborative networks in the field. The primary aim was to offer a thorough perspective on the existing knowledge landscape surrounding *F. racemosa*, facilitating the identification of gaps and guiding future research efforts. Additionally, the study focused on strategic decision-making in diverse areas such as agricultural practices, environmental conservation, and pharmaceutical applications.

Data Sources and Tools for Insights

The analysis of research literature on *F. racemosa* through bibliometric methods offers valuable insights into the breadth, impact, and trends characterizing scholarly works on this species. This study employed a bibliometric approach using the precise search term "*Ficus racemosa*" conducted via Dimensions.ai, covering from 2002 to 2023. Data extraction occurred in the second week of January 2024, encompassing research conducted over the preceding two decades. The research methodology involved a diverse set of analytical tools including Microsoft Excel, integrated tools of Lens.org, and VosViewer. Initial data organization and preliminary

assessments were conducted using Microsoft Excel, while more sophisticated analyses were performed using Lens.org and VosViewer (Version 1.6.19), as indicated by previous studies (Balcázar-Zumaeta et al., 2023; Barragán-Ocaña et al., 2023; Sarjidan et al., 2023). These tools facilitated the exploration of citation networks, patterns of co-authorship, and the creation of visual representations to elucidate bibliographic data. The study's specific areas of focus were identified through integrated features within lens.org, allowing for a comprehensive examination of key research themes and domains.

Comprehensive Data Insights

A thorough analysis was conducted on a diverse set of 325 scholarly publications, including articles, chapters, preprints, and proceedings, derived from diverse scholarly sources including books and journals. The research on this specific species is highlighted by its remarkable impact, evident in an impressive average of 14.60 citations per document. The exploration revealed a total of 1175 authors actively engaged in *F. racemosa* research, emphasizing collaborative efforts within this specific domain. A total of 13 authors distinguished themselves through independent contributions, demonstrating both competence and sustained interest in the subject. The scholarly outputs are distributed across 245 journals associated with 341 organizations spanning 35 countries. This expansive network of contributors and institutions emphasizes the ongoing exploration of the subject matter, reinforcing the enduring relevance of *F. racemosa* in contemporary scientific discourse. The comprehensive insights derived from this exploration on the significance and sustained interest in research focused on *F. racemosa*.

Temporal Analysis and Growth Dynamics

A total of 325 documents were retrieved through extensive searches conducted across bibliographic databases using Dimensions. ai. These documents encompassed various forms of scholarly works, including 307 articles and 12 chapters. Analysis revealed an exponential growth pattern [$R^2=0.8419$] in publication output spanning from 2002 to 2023 (Fig. 1). The peak years of scholarly document publication were observed in 2023 and 2022, with 31 and 30 publications emerging, respectively. These findings emphasized the comprehensive dissemination of research on *F. racemosa*, with articles serving as the predominant mode of communication, complemented by chapters. The continuous increase in publications, alongside the diverse range of scholarly documents, reflected the enduring and substantial interest of the scientific community in this field.

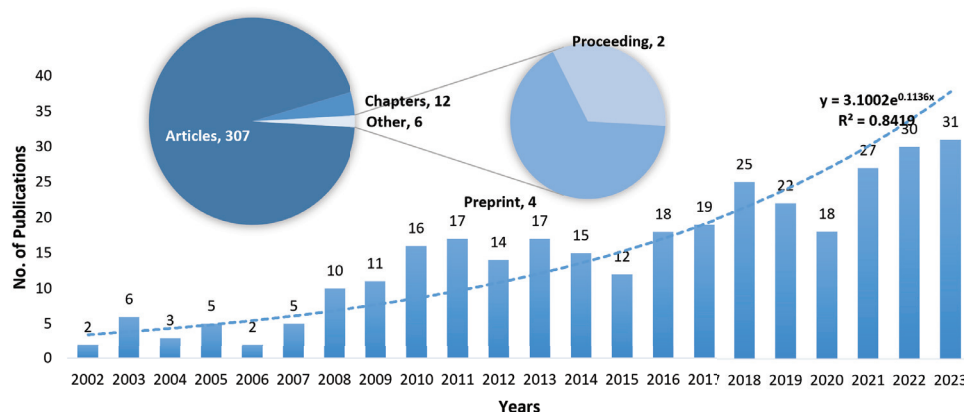


Fig. 1 Publication trends and distribution types in *F. racemosa* research

Citation Analysis

The analysis of citations in research on *F. racemosa* from 2002 to 2023 revealed a dynamic pattern of citation counts evolving during this time scale. Initially, from 2002 to 2008, there was an inconsistent growth in citations, although with intermittent fluctuations of research interest during this period. The exponential rise in citation count was observed in 2003, possibly indicating enhanced remarkable breakthroughs in the field. However, this was followed by a rapid decline in 2004, suggesting potential plateaus in research attention (Fig. 2). In 2008, there was a remarkable increase in citations

for research on *F. racemosa*, reaching 440 citations. However, from 2016 to 2023, a distinct trend emerged, characterized by a significant decline in citation counts, particularly evident in the substantial reduction observed in 2022 and 2023. This decline may indicate a shift in research priorities, emerging trends, or the necessity for fresh perspectives in *F. racemosa* research. The data illustrated fluctuations in citation numbers, highlighting pivotal moments when research on *F. racemosa* made a significant impact. Peaks in citations during specific years denote remarkable contributions and significance, while variations emphasize the evolving popularity of the field over time.

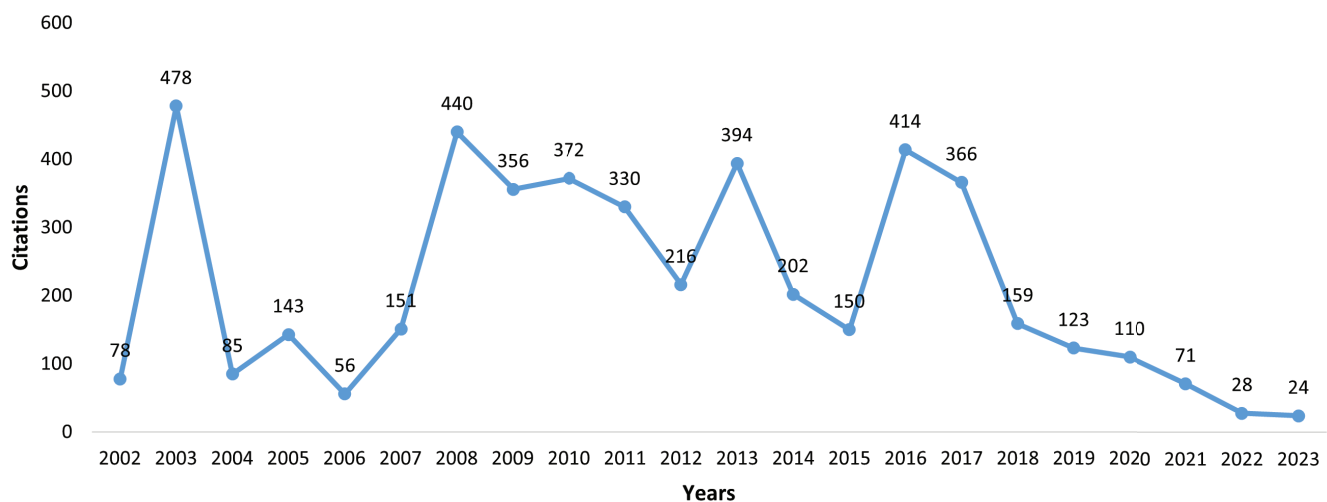


Fig. 2 Citation trends for *F. racemosa* research over time

Country-wise Publication Analysis

The assessment of scholarly output regarding research on *F. racemosa* across 35 nations has revealed intriguing patterns and offered valuable insights into global

research contributions and their impact. India emerged as the most prominent country, with a total of 107 articles, followed closely by China with 31 scholarly articles. Moreover, Indonesia, Bangladesh and Thailand exhibited remarkable contributions, having 13, 10, and 9 publications, respectively. Furthermore, Sri

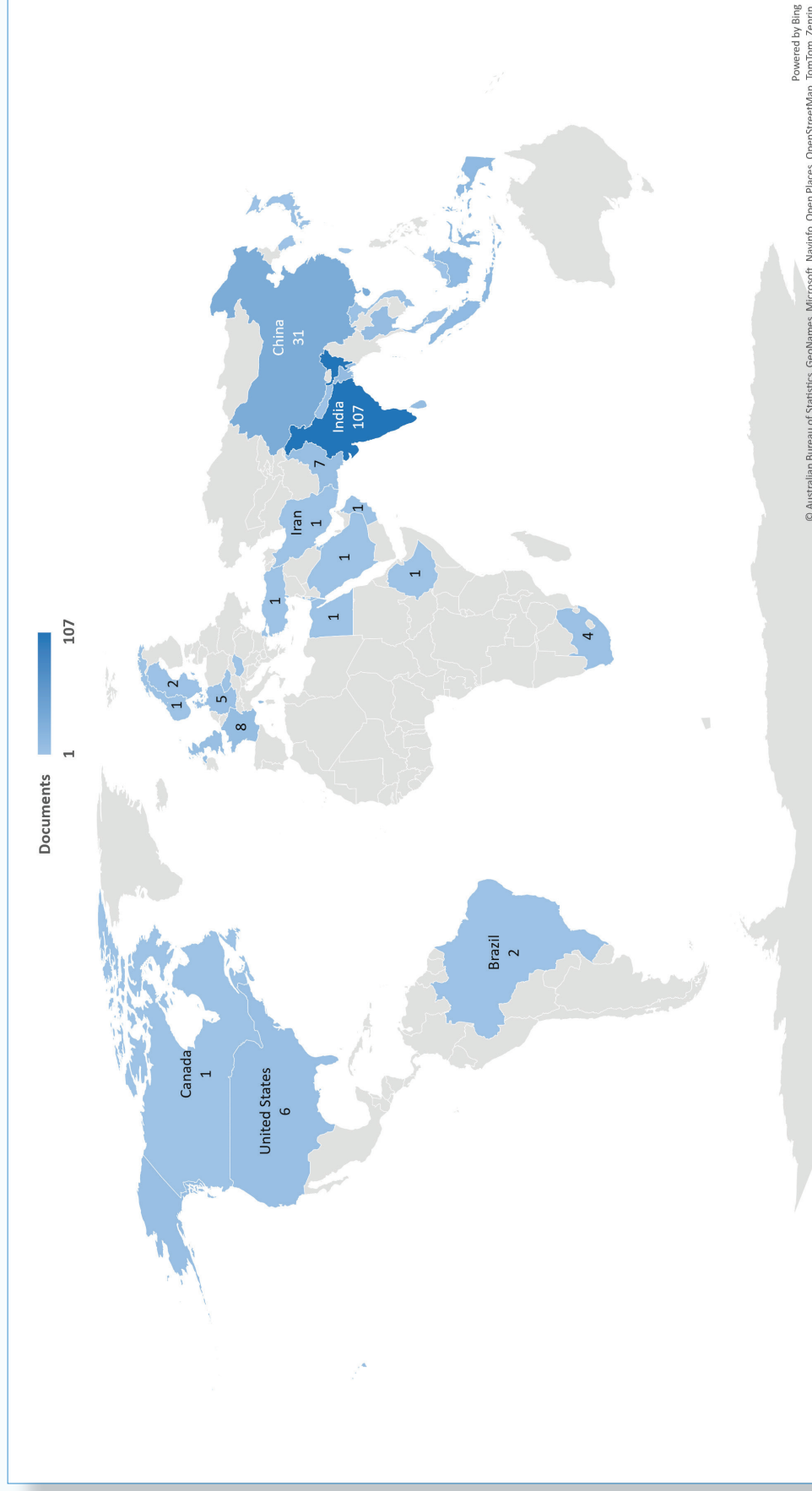


Fig. 3 Global distribution of research on *F. racemosa*

Lanka, France, and Australia each contributed 8 publications to this research domain. Additionally, the United Kingdom, Pakistan, and the United States also made substantial contributions to the scholarly output on *F. racemosa* (Fig. 3). This analysis highlighted the diverse global landscape of *F. racemosa* research, illustrating how contributions from various nations are influenced by the maturity of their research ecosystem, the availability of resources, and their strategic objectives.

Most Prominent Authors

Among the prominent authors, Renee M. Borges attained the top position with 19 documents with 405 citations, followed by Faiyaz Ahmed with 12 documents and 221

citations. Asna Urooj ranked third with 11 documents and 205 citations, followed by Anusha Krishnan, who published 8 documents gaining 149 citations. Moreover, Mahua Ghara, Yuvaraj Ranganathan, Rui-Wu Wang, Qishi Song, M. Pal, and Derek W. Dunn, each contributed significantly with four scholarly documents during this period (Fig. 4). The diverse group of authors exploring *F. racemosa* signified the extensive spectrum of scholarly production in this specific area of study, highlighting the expertise and perspectives contributing to the research on this plant species. Overall, these findings emphasized the substantial contributions made by these authors to the understanding and knowledge of *F. racemosa*.

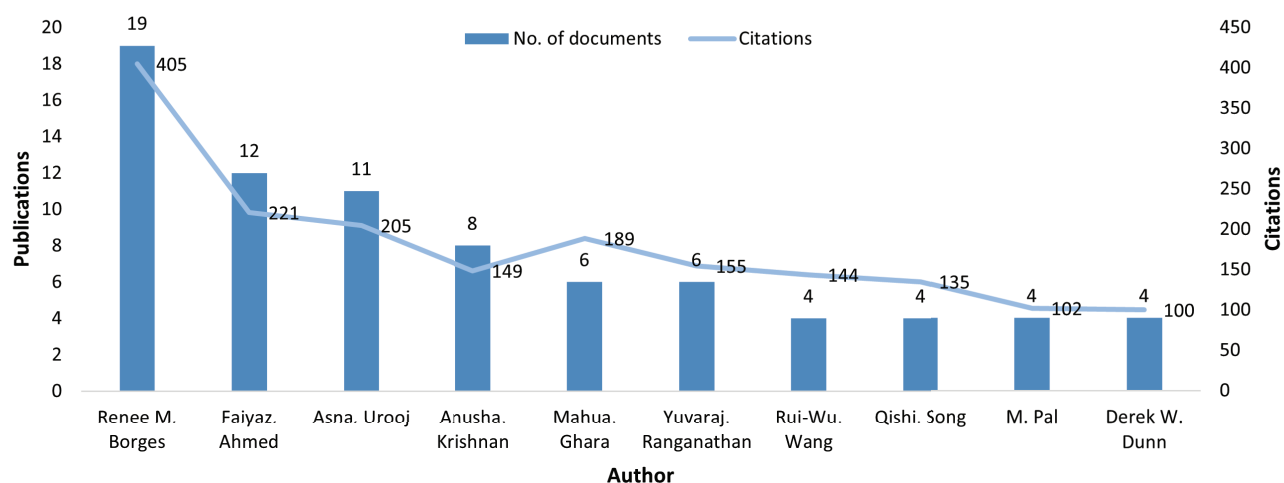


Fig. 4 Most prominent authors based on research contributions to *F. racemosa*

Highly Cited Articles

The top 10 highly cited research articles on *F. racemosa* provided a comprehensive overview of its diverse applications and properties. The most highly cited article investigated the

influence of *F. racemosa* on the "The antioxidant activity and free radical scavenging potential of two different solvent extracts of *Camellia sinensis* (L.) O. Kuntz, *Ficus bengalensis* L. and *Ficus racemosa* L." published in the journal

Food Chemistry in 2008, acquiring a total of 227 citations (Manian et al., 2008). The second-most cited article, "Plant Medicines of Indian Origin for Wound Healing Activity: A Review" was published in The International Journal of Lower Extremity Wounds in 2003, received 165 citations (Biswas et al., 2003). Moreover, the third-most cited article, "A cross-cultural study: anti-inflammatory activity of Australian and Chinese plants" received 137 citations, and it was published in the Journal of Ethnopharmacology in 2003 (Li et al., 2003).

Additionally, several research articles were observed that have more than 100 citations (Elliott et al., 2003; Chen et al., 2009; Thakur et al., 2017). Furthermore, various studies published in different journals have fewer citations of less than 100 (Veerapur et al., 2011; Udayanga et al., 2013; Trinh et al., 2016) (Table 1). These pivotal studies, accumulating a substantial total citation count, collectively highlighted the multifaceted nature of *F. racemosa* and its relevance across various scientific domains.

Table 1 Top 10 highly cited research articles published on *F. racemosa* and its relevance

Rank	Title	Journal	Year	Citation	References
1.	The antioxidant activity and free radical scavenging potential of two different solvent extracts of <i>Camellia sinensis</i> (L.) O. Kuntz, <i>Ficus bengalensis</i> L. and <i>Ficus racemosa</i> L.	Food Chemistry	2008	227	Manian et al., 2008
2.	Plant Medicines of Indian Origin for Wound Healing Activity: A Review	The International Journal of Lower Extremity Wounds	2003	165	Biswas et al., 2003
3.	A cross-cultural study: anti-inflammatory activity of Australian and Chinese plants	Journal of Ethnopharmacology	2003	137	Li et al., 2003
4.	Selecting framework tree species for restoring seasonally dry tropical forests in northern Thailand based on field performance	Forest Ecology and Management	2003	131	Elliott et al., 2003

Rank	Title	Journal	Year	Citation	References
5.	Multifunctional graphene quantum dots for combined photothermal and photodynamic therapy coupled with cancer cell tracking applications	RSC Advances	2017	112	Thakur et al., 2017
6.	Larvicidal activity of green synthesized silver nanoparticles using bark aqueous extract of <i>Ficus racemosa</i> against <i>Culex quinquefasciatus</i> and <i>Culex gelidus</i>	Asian Pacific Journal of Tropical Medicine	2013	107	Velayutham et al., 2013
7.	Private channel: a single unusual compound assures specific pollinator attraction in <i>Ficus semicordata</i>	Functional Ecology	2009	100	Chen et al., 2009
8.	Screening for potential α -glucosidase and α -amylase inhibitory constituents from selected Vietnamese plants used to treat type 2 diabetes	Journal of Ethnopharmacology	2016	94	Trinh et al., 2016
9.	What are the common anthracnose pathogens of tropical fruits?	Fungal Diversity	2013	93	Udayanga et al., 2013
10.	Antidiabetic effect of <i>Ficus racemosa</i> Linn. stem bark in high-fat diet and low-dose streptozotocin-induced type 2 diabetic rats: A mechanistic study	Food Chemistry	2011	85	Veerapur et al., 2011

Most Active Journals

The present study showed the top journals of *F. racemosa* research based on their impact factor, publications, and citations. Acta Oecologica by Elsevier had emerged as the foremost journal, boasting an impressive impact factor of 2.23 and publishing 7 documents, with 90 citations on this topic. Subsequently, the Journal of Ethnopharmacology, also from Elsevier, maintained a significant presence

with an impact factor of 4.81, contributing 5 documents and gaining 327 citations, marking its significant influence in *F. racemosa* research. The Pharmacognosy Journal by Wolters Kluwer Health primarily focused on crude extracts from herbs had an impact factor of 3.55, along with 5 published documents and 30 citations related to *F. racemosa*, underscoring its considerable contribution to this area of research. Moreover, Plos One, Pharmaceutical Biology, Advances in

Traditional Medicine, Research Journal of Pharmacy and Technology, and Indian Drugs are from their corresponding publishers such as the Public Library of Science, Taylor & Francis, Hindawi, Scipharm Publishers and Indian Drugs Manufacturers' Association each contributing 4 documents on this topic of interest (Table 2).

Table 2 Top journals in *F. racemosa* research exhibited the highest published documents and citations

Rank	Journal	Publisher	Impact Factor	Documents	Citations	Average Citations Per Article
1.	Acta Oecologica	Elsevier	2.23	7	90	12.86
2.	Journal of Ethnopharmacology	Elsevier	4.81	5	327	65.40
3.	Pharmacognosy Journal	Wolters Kluwer Health	3.55	5	30	6.00
4.	Plos One	Public Library of Science	3.75	4	112	28.00
5.	Pharmaceutical Biology	Taylor & Francis	2.40	4	92	23.00
6.	Advances in Traditional Medicine	Hindawi	2.75	4	37	9.25
7.	Research Journal of Pharmacy and Technology	Scipharm Publishers	1.51	4	21	5.25
8.	Indian Drugs	Indian Drugs Manufacturers Association	-	4	7	1.75
9.	Evidence-Based Complementary and Alternative Medicine	Hindawi	2.72	3	107	35.67
10.	Phytotherapy Research	Wiley	4.85	3	91	30.33

Top Productive Organizations

In the present study, the data insights represented a comprehensive overview of top organizations in *F. racemosa* research. Among the organizations, the Indian Institute of Science Bangalore leads with 19 documents and 426 citations, followed by Xishuangbanna Tropical Botanical Garden with 16 documents and 351 citations. The University of Mysore and Kunming Institute of Zoology published 12 scholarly documents with 218 citations, and 11 documents with 260 citations respectively.

Other organizations like the University of Chinese Academy of Sciences and Jadavpur University, while France's Centre D'Écologie Fonctionnelle Et Évolutive and École Nationale Supérieure De Chimie De Montpellier, Yunnan University of Finance and Economics and Anna University, Chennai showed significant interest on this topic. This analysis highlights global collaboration and the pursuit of both quantity and quality in research impact, shaping the future of the academic and research domain (Table 3).

Table 3 Top organizations' contributions to *F. racemosa* research

Rank	Organization	Country	Documents	Citations	Average Citations Per Article
1	Indian Institute of Science Bangalore	India	19	426	22.42
2	Xishuangbanna Tropical Botanical Garden	China	16	351	21.94
3	University of Mysore	India	12	218	18.17
4	Kunming Institute of Zoology	China	11	260	23.64
5	University of Chinese Academy of Sciences	China	7	95	13.57
6	Jadavpur University	India	6	181	30.17
7	Centre D'Écologie Fonctionnelle Et Évolutive	France	5	215	43.00
8	École Nationale Supérieure De Chimie De Montpellier	France	5	207	41.40
9	Yunnan University of Finance and Economics	China	4	126	31.50
10	Anna University, Chennai	India	3	261	87.00

Most Prominent Fields of Study

In this analysis, the co-occurrence of terms within prominent fields of study was examined in a dataset comprising 325 scholarly documents extracted from lens.org. The research findings, based on document count, highlighted diverse subjects. The term *Ficus* was prominently featured in 305 documents, indicating a central research theme. Biology as a term, with 288 documents, explored various biological phenomena beyond *Ficus*. Traditional medicine, represented by 217 documents, investigated the medicinal properties of plants, potentially including *Ficus*. The keyword Botany, comprising 156 documents, focused on plant classification, structure, and function, complementing the specific study of *Ficus*. The term Chemistry, with 132 documents,

emphasized understanding the chemical composition of *Ficus* and related plants. Medicine as a term, with 105 documents, explored the health benefits or applications of *Ficus*. Ecology, with 80 documents, explored the broader environmental context of *Ficus* and other plants. The family Moraceae, including *Ficus*, was studied in 67 documents. Bark, in 61 documents, involved investigations into the chemical composition, medicinal properties, or ecological roles of various plant species. Phytochemicals, in 59 documents, focused on chemical compounds in plants, exploring their presence in *Ficus* (Fig. 5). The comprehensive analysis highlighted a multidisciplinary approach, emphasizing biological, chemical, and medicinal aspects, representing connection across various fields in understanding *Ficus* and related plant species.

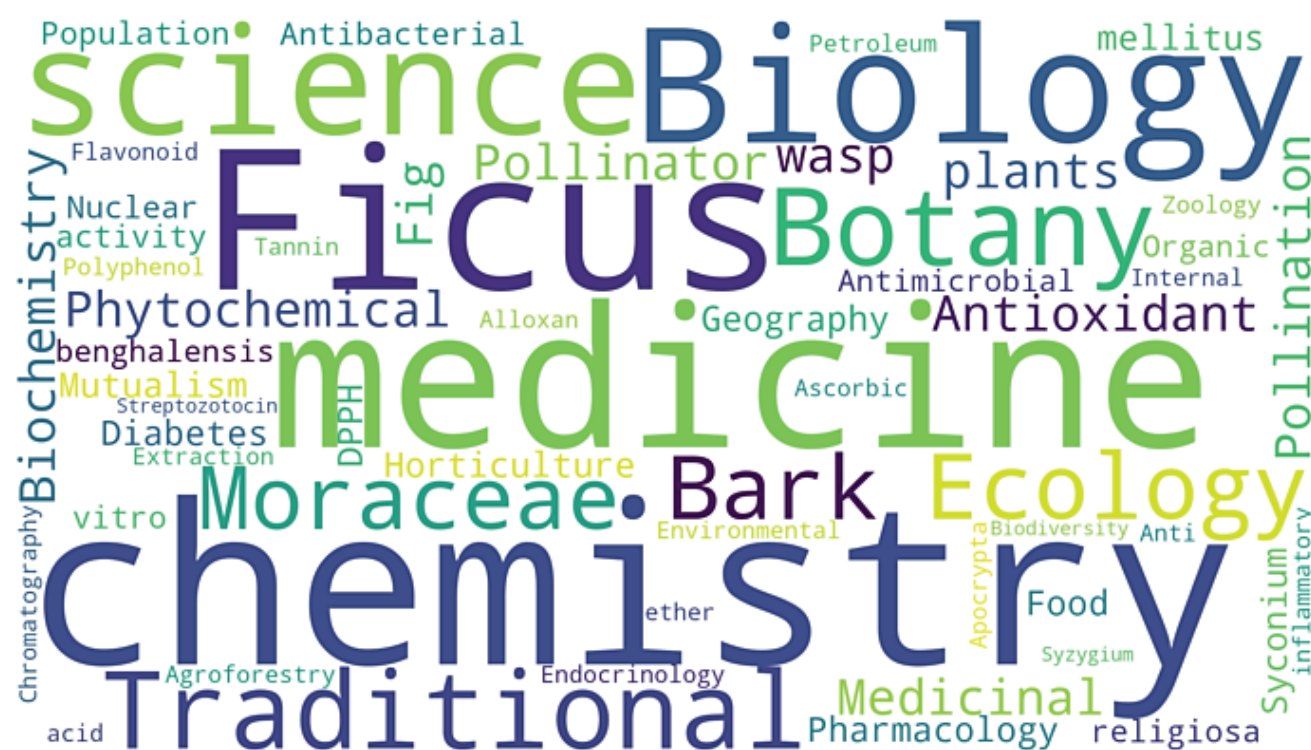


Fig. 5 Terms co-occurrence analysis within prominent terms

Research Collaboration Networks

Authors' Collaboration Network

The investigation involved a comprehensive examination of 1175 authors, elucidating a significant presence of researchers within the specific subject domain. The assessment employed citation analysis to measure the similarity between authors based on shared citations. The collaborative network was established from a subset of 16 authors among the 28 who had authored a minimum of three documents on *F. racemosa*, each gathering a minimum of three citations. The resultant

network manifested two distinct clusters, as illustrated in Fig. 6, delineating groups of interconnected and collaborative authors. Cluster 1, the larger of the two, comprised 11 members, while cluster 2 encompassed 5 members. Renee M. Borges emerged as the prominent author, having the highest total link strength at 229, followed by Anusha Krishnan and Mahua Ghara, with respective total link strengths of 122 and 118. These findings clarify a diverse research community characterized by varying degrees of specialization and collaborative engagement.

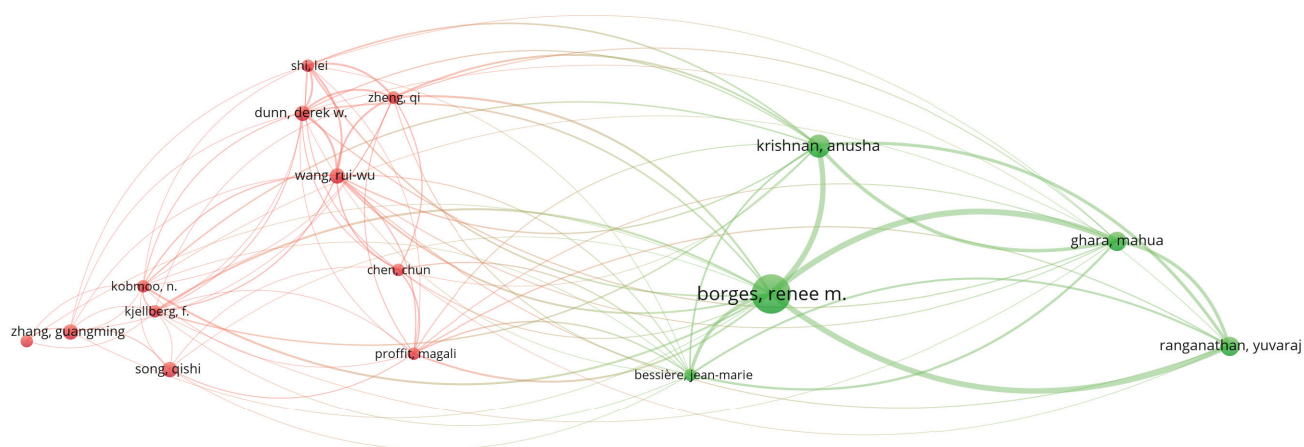


Fig. 6 Collaborative network among the authors on *F. racemosa*

Journal-wise Collaboration Network

In the analysis of the journal-wise collaboration network, a dataset of 245 journals dedicated to *F. racemosa* research were elucidated 19 interlinks among 31 journals through rigorous citation analysis.

The established criteria mandated a minimum of two documents and ten citations on *F. racemosa*, resulting in the discernment of four discrete clusters within the journal-wise collaboration network. Cluster 1 and 2 emerged as the most substantial clusters, each comprising six journals, followed by cluster 3 and cluster 4, containing five and four

journals, respectively. This clustering revealed distinctive thematic concentrations within *F. racemosa* research, highlighting specialized areas of focus. The journal *Phytotherapy Research* demonstrated the highest connection strength at 22, signifying its pivotal role in facilitating collaborative initiatives. Furthermore, the journals *Pharmaceutical*

Biology and *PLOS One* exhibited remarkable influence, with total link strengths of 22 and 16, respectively (Fig. 7). The network analysis provided insights into the thematic strengths and collaborative prospects among journals engaged in *F. racemosa* research, offering a nuanced understanding of the scholarly landscape within this domain.

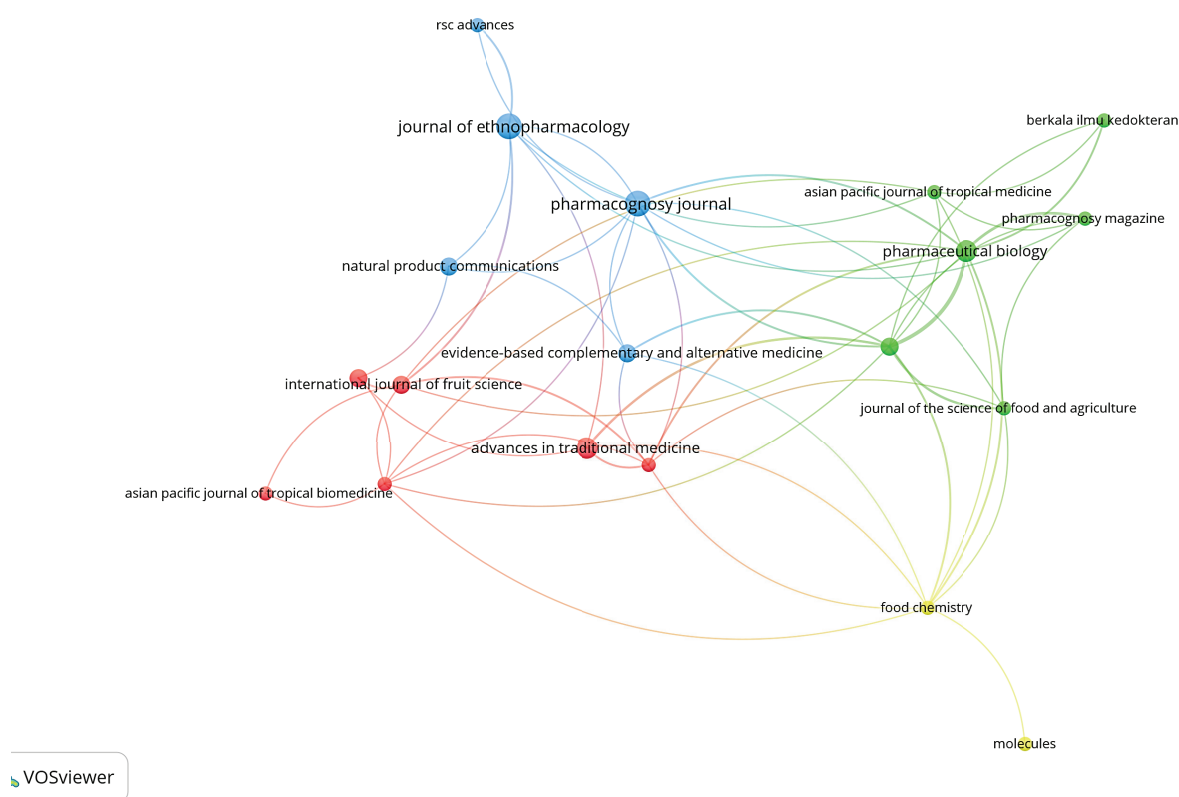


Fig. 7 Journal-wise collaboration network analysis on *F. racemosa* research

Organizational Collaborative Network

Utilizing citation analysis, an exploration of the organizational collaboration network within the *F. racemosa* study domain was conducted. The comprehensive investigation encompassed 341 organizations, revealing relationships among 7 out of 9 organizations. Criteria

stipulated a minimum of four documents and four citations on *F. racemosa* research. The resultant organizational collaboration network exhibited two distinct clusters (Fig. 8). Cluster 1, comprising four organizations, emerged as the largest and indicated a remarkable level of inter-organizational cooperation. Cluster 2 consisted of three organizations, demonstrating closely-knit

connections among them. The Kunming Institute of Zoology appeared as the central hub within the network, showing the highest connection strength at 84. The Indian Institute of Science Bangalore ensured the second-highest overall connection strength of 73 links, followed by Xishuangbanna Tropical Botanical Garden with 72 links. Understanding these

collaborative networks is crucial for adopting successful partnerships and advancing research on *F. racemosa*. Researchers, institutions, and policymakers may benefit from insights gathered from these networks to strategically enhance collaborative endeavors and drive research progress.

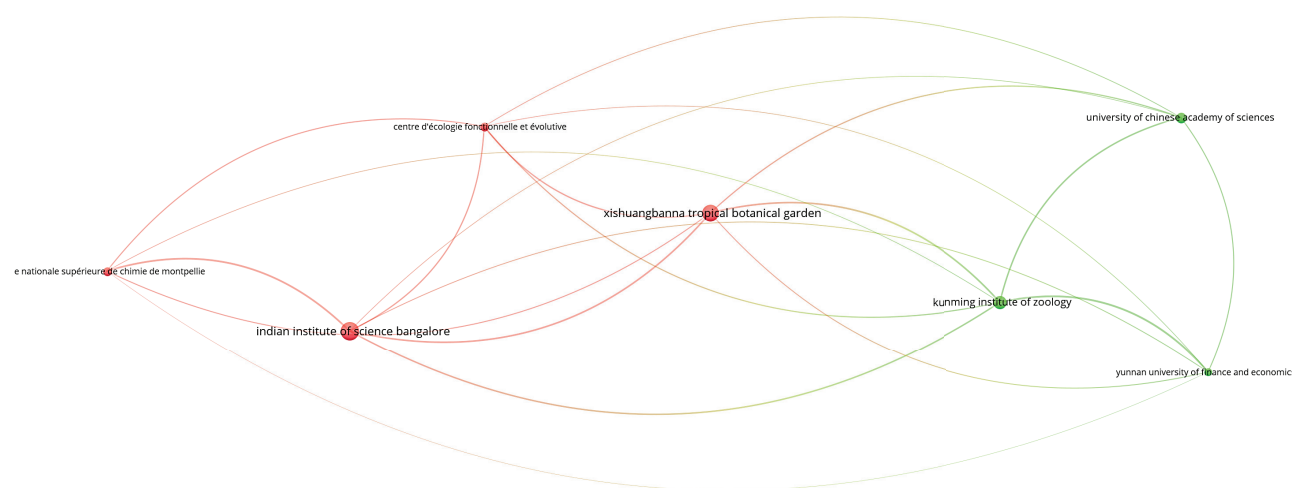


Fig. 8 Clusters of collaborative institutions for *F. racemosa* research

Country-wise Collaboration Network

In the assessment of country-wise collaboration networks within the *F. racemosa* research, a thorough analysis comprised 35 countries, identifying 14 linkages. The inclusion criteria required at least three documents on *F. racemosa* with a minimum of three citations. The study exhibited four distinct clusters, each characterized by varied collaboration levels and research focus, identified through citation analysis. Clusters 1 and 2 comprised

six and four nations, respectively, indicating an evident level of collaboration between them. Clusters 3 and 4 each comprised two countries, representing more concentrated collaboration networks (Fig. 9). Furthermore, India and China exhibited the most robust connection strength, with 210 and 115 links, respectively, emphasizing their central roles in this analysis. The analysis underscores the significance of collaborative research in enhancing the understanding of *F. racemosa* research by revealing the global landscape and interconnectedness of scientific endeavors.

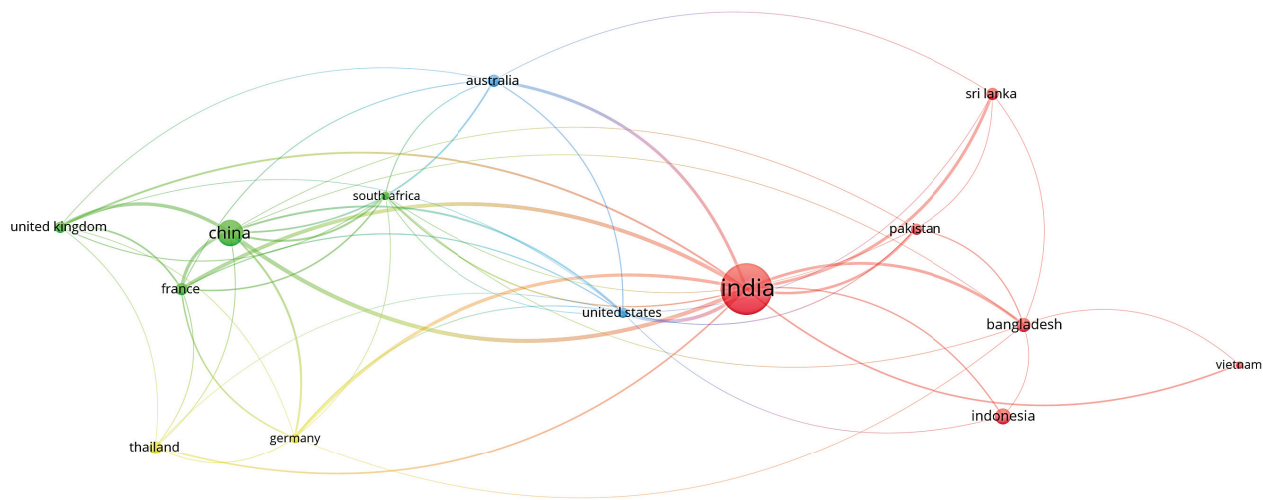


Fig. 9 Country-wise collaboration network in *F. racemosa* research

CONCLUSION

In this study, the bibliometric analysis has provided a comprehensive and insightful overview of the research landscape associated with *Ficus racemosa*. This plant species has gained significant attention, and the exploration of scholarly literature has facilitated its usability into diverse implications across agricultural practices, environmental conservation, and pharmaceutical domains. Analyzing 325 scholarly publications from 2002 to 2023 revealed key trends, contributors, and collaborative networks, with a peak in scholarly document publication in 2023, signaling increased interest in the subject. *F. racemosa* research was found distinguished by an average of 14.60 citations per document, with a remarkable increase in 2008, highlighting its enduring impact. India emerged as the most prominent country in terms of country-wise publication, with outstanding contributions from authors like Renee M. Borges and Faiyaz Ahmed, while journals such as *Acta Oecologica*

and organizations like the Indian Institute of Science Bangalore played pivotal roles in shaping the research landscape. Furthermore, the collaboration networks analysis was focused on the interconnected web of authors, journals, organizations, and countries actively engaged in *F. racemosa* research. This collaborative engagement, characterized by varying degrees of specialization, underscores the interdisciplinary nature of the field and points towards potential opportunities for future collaborations and knowledge exchange. The identification of highly cited articles, active journals, and productive organizations provides valuable insights for researchers, policymakers, and practitioners. The study's contribution extends beyond the mere exploration of past trends; it serves as a roadmap for future research efforts, guiding strategic decision-making in diverse areas associated with *F. racemosa*.

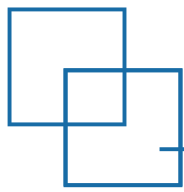
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CHAPTER 03

Soil Properties



INTRODUCTION

Soil is a complex matrix generated by the weathering of rocks that compose the Earth's crust's outer layer. It is generated through the dynamic interplay of minerals, organic matter, air, water, and other living species. It promotes plant growth due to its nature and the availability of nutrients. Plant development and yield are enhanced when the soil is nutrient rich (The State of Queensland, 2013). Soil, in addition to serving as a medium for plant growth, play an important role in gaseous exchange by absorbing and releasing gases such as carbon dioxide, oxygen, and methane. They can also hold water, which is an important resource for plant growth. Soils are host to various living organisms such as animals, fungi, bacteria, and other organisms because of their qualities. As a result of the presence of numerous living creatures, organic matter is constantly recycled through breakdown and accumulation. Soil is also a valuable basis for construction material from a commercial perspective (Soil Science Society of America, 2023).

Soil is made up of biotic and abiotic constituents, which comprise live creatures as biotic factors and minerals, organic matter, gas, and water as abiotic ones. All the components are responsible for plant growth and serve a significant role in preserving soil quality (Needelman, 2013). The percentages of each component vary amongst soil types, such as sandy, clayey, loamy, silty, and so on. The quantities of distinct components in soil are determined by the sites where the soil is available and the parent material from which it forms. The area where the soil is available and the parent material from which it forms determines the respective proportions of individual components in the soil. For instance, there are many different types of soils available in India. The first type is the alluvial soil which covers 46% of the Indian soil area. Rocks of the Himalayas are the parent material, and this kind of soil formation occurs by silt deposition by Indo-Gangetic-Brahmaputra Rivers. The next kind is the black soil which is formed from volcanic rocks in the Deccan Plateau. These soils are rich in clay and cover 16.6% of the total soil cover in India. The other types of soil include red and yellow soil, desert soil, laterite soil, peaty and marshy soil, alkaline soil, and mountain soil (Bhattacharyya et al., 2013).



The percentage composition, quantity, and quality of the components or nutrients in the soil all affect how fertile it is. The fertility of the soil in turn determines the type of crop that can grow in it and its yield and nutritional parameters. Ogundola et al., (2021) found different concentrations of essential oil from the shoots of *Solanum nigrum* L. that were grown in different types of soil. Due to the change in the oil content of the shoot, the free radical scavenging activity varied. It was reported in the study that plants grown of clay loam soil showed the highest radical scavenging activity. Similar results were obtained from extracts of plant shoots grown on clay loam soil for ABTS radical scavenging. Andrade et al., (2011) also reported a similar phenomenon in the case of *Piper dilatatum* Rich. They showed that the essential oil composition of plants collected from different regions of Amazon, Brazil during rainy seasons varied due to environmental variations including variations in soil type. Jimoh et al., (2019) reported that *Amaranthus caudatus* L. exhibited the highest phytochemical yield when grown in clayey loam soil. A similar thing was replicated for the antioxidant activity of the plant extract. Zargoosh et al., (2019) showed that the interaction of site and elevation played a significant effect on the antioxidant potential and total phenol content in *Scrophularia striata* Boiss. The antioxidative capacity was indirectly correlated to elevation, phosphorous, potassium, organic carbon, organic matter, and nitrogen levels for the first site. Similarly, the acidity content had the highest negative correlation with antioxidant capacity. The lime and sand percentage of soil was also negatively related to the phytochemical content.

It has previously been demonstrated that a plant's environment has an impact on the number of secondary metabolites it produces and, ultimately, on the phytochemical composition of that plant (Walker et al., 2001; Srivastava and Shym, 2002; Dorri et al., 2009). The temperature and the humidity of the area in which a plant grows affect the phytochemical profile of the plant (Fox et al., 1999). How the environment regulates phytochemical composition and quantity of plants is yet to be completely understood. Yet theories state that environmental factors may influence metabolic processes in plants which thereby affects the phytochemical content. At different altitudes, even the same plant shows different growth characteristics due to differences in light intensity, exposure to radiation, wind speed, humidity, water content in soil, and nutrient content in soils. The microbial composition of the soil may also affect the plant phytochemicals. Makgato et al., (2020) showed that inoculation of beneficial soil microbes like *Rhizobium* into soil can also stimulate plant phytochemical content. They showed that total phenolic

and flavonoid content increased because of *Rhizobium* inoculation in soil as compared to control. This occurred even though plant biomass and nitrogen fixation did not show any increase. Similarly, Egamberdieva et al., (2015) have reviewed in their book that plant growth promoting rhizobacteria helps plants by improving their salt and heavy metal tolerance, preventing plant diseases, and boosting soil fertility. In the case of medicinal plants specifically, they can enhance the phytochemical levels by inducing secondary metabolite production. It is thus beneficial to enrich soils with beneficial microbes which can further be utilized for commercial purposes. Thus, it is evident that environmental variations including humidity, temperature, radiations as well and soil microbiomes influence the secondary metabolite production of medicinal plants and hence their phytochemical production. These attributes are beneficial to understanding plant physiology and the best possible conditions for the cultivation of medicinal plants. In the current study, emphasize on studying the physicochemical variations in soil quality from different altitudes of sampling sites is given in Table 2. Soil physicochemical parameters like pH, electrical conductivity, organic carbon content, available nitrogen, phosphorous, potassium, sulphur and micronutrients, total moisture content, heavy metal, and bulk density have been studied to understand the quality at different altitudes and how they may influence vegetation in the different sites.

Sampling Sites

The bulk soil and plants (along with the rhizospheric soil) were collected from a total of 26 sites. The numbering of the sites, name of sites along coordinates are given in Table 1.

Table 1 Study sites and coordinates

S.No.	States	Site	Site Code	Latitude	Longitude
1.	Uttarakhand	Gomukh	UK -S1	30.56790	79.03081
2.		Gangotri	UK-S2	31.03920	78.74655
3.		Uttarkashi	UK-S3	30.74619	78.48377
4.		Devprayag	UK-S4	30.1358	81.1218
5.		Haridwar	UK-S5	29.9169	81.5315

S.No.	States	Site	Site Code	Latitude	Longitude
6.	Uttar Pradesh	Bijnor	UP-S1	29.2857	82.3243
7.		Narora	UP-S2	28.1465	83.1315
8.		Badaun	UP-S3	27.9394	83.5612
9.		Farrukhabad	UP-S4	27.4104	84.496
10.		Bithoor	UP-S5	26.6159	85.1242
11.		Dalmau	UP-S6	26.3485	85.5979
12.		Prayagraj	UP-S7	25.2537	86.2076
13.		Mirzapur	UP-S8	25.8588	87.0908
14.		Varanasi	UP-S9	25.1518	87.396
15.		Ballia	UP-S10	25.3546	87.9107
16.	Bihar	Revelganj	BH-S1	25.4388	88.2213
17.		Patna	BH-S2	25.3808	88.3809
18.		Barh	BH-S3	25.2311	88.3895
19.		Bahachoki	BH-S4	25.1782	88.1959
20.		Farka	BH-S5	25.2323	78.8535
21.	Jharkhand	Sahibganj	JH-S1	25.1461	79.6282
22.	West Bengal	Farraka	WB-S1	24.8227	80.277
23.		Hazarduari	WB-S2	23.9969	81.1218
24.		Mayapur	WB-S3	23.4129	81.5315
25.		Hoogly	WB-S4	22.8491	82.3243
26.		Gangasagar	WB-S5	22.1774	83.1315

The temperature of a particular site is dependent on its altitude as well as climate conditions. At the time of sample collection, the temperature of the sites as well as altitude

of the sites as shown in live GPS map via GPS map camera app was noted down. The altitude and temperature of different sites for sample collection are shown in the Table 2.

Table 2 Temperature and altitude of different sampling sites

Site	Temperature (°C)	Altitude (m)
UK -S1	09	3794
UK -S2	17	2506
UK -S3	18	1232
UK -S4	23	1014
UK -S5	34	265

Site	Temperature (°C)	Altitude (m)
UP-S1	29	217
UP-S2	31	179
UP-S3	25	162
UP-S4	27	136
UP-S5	28	113
UP-S6	31	91
UP-S7	33	91
UP-S8	32	91
UP-S9	38	65
UP-S10	34	67
BH-S1	25	69
BH-S2	25	36
BH-S3	28	30
BH-S4	30	18
BH-S5	25	23
JH-S1	25	17
WB-S1	28	32
WB-S2	30	14
WB-S3	27	8
WB-S4	30	9
WB-S5	31	3

Soil Analysis

Physicochemical Analysis of Soil

Total Moisture Content (%)

Soil moisture content, often known as water content, is an indication of the quantity of water in the soil. Moisture content is stated as a proportion of the mass of water contained in the pore spaces of soil to the solid mass of particles in that substance. The mass of the sample is determined using a reference

temperature of $110 \pm 5^\circ\text{C}$. Almost all soil tests detect the natural moisture content of the soil, which is critical knowledge for all soil mechanics. The natural moisture content indicates the condition of the soil in the field (Hossain et al., 2022).

Apparatus and equipment required: Non-corrodible vented container, thermostatically controlled drying oven that maintains

temperatures between 105°C to 115°C, Balance of sufficient sensitivity (sensitive to 0.01 g) and container handling apparatus.

Procedure

1. Clean, dry and weigh W_1 the container. The balance needs to be tared before it is used to measure the weight.
2. Weigh W_2 a sample of the specimen in the container.
3. Keep the container in the oven for 24 hours. Dry the specimen to a constant weight, maintaining the temperature between 105°C to 115°C (The time will vary with the type of soil, but 16 to 24 hours is usually sufficient)
4. Record the final constant weight W_3 of the container with the dried soil sample. Peat and other organic soils should be dried at a lower temperature (approximately 60°C) for a longer period.

Calculations

1. Weight of the container = W_1 g
2. Weight of the container + Weight of the wet sample = W_2 g
3. Weight of the container + Weight of the dried sample = W_3 g
4. Weight of water in the soil sample = $W_2 - W_3 = M_w$ g
5. Weight of the dry soil = $W_3 - W_1 = M_s$ g
6. Moisture content in the given soil sample = $(M_w \text{ g} / M_s \text{ g}) \times 100\%$

Bulk Density

Bulk density is a commonly measured soil property by agriculturalists and engineers. High

bulk density soils are soils with little pore space, so water infiltration is reduced, root penetration is inhibited, and aeration is restricted – reducing agricultural productivity. Low bulk density soils are easily compacted and may settle considerably to the detriment of roads, sidewalks, and building foundations (Bowen, 2016).

Apparatus and equipment required: Top load balance, soil spatula, 100ml graduated measuring cylinder, 2x50 ml beaker, paper towels and mud bucket.

Procedure

1. Add slightly more than 50 ml of the soil sample to 50 ml beaker.
2. Clean and thoroughly dry a 100 ml graduated cylinder. Weigh and record weight (A).
3. Slowly add soil sample to pre-weighed graduated cylinder to the 10 ml line. Compact the soil by dropping onto a padded surface like a book, notebook, etc. at least ten times from a height of about 2-3 inches.
4. Repeat this process in 10 ml intervals until you reach the 50 ml mark.
5. Use a soil spatula to level the top of the sample in the graduated cylinder and add soil with the spatula until the top of the soil sample is exactly even with the 50 ml line – this is the bulk volume of compacted soil (B) (1 ml = 1 cm³).
6. Weigh and record graduated cylinder plus compact soil weight (C).
7. After drying the beaker, place any soil sample that is still in it back into the

sample storage container.

8. Return 50 ml sample in graduated cylinder to 50 ml beaker. Remove all of sample within graduated cylinder.
9. Slowly pour approximately 25 ml of soil sample from beaker into water in the graduated cylinder. Gently stir soil/water mixture to remove any air bubbles. Add the second 25 ml of soil sample and stir again to remove air bubbles.

Calculations

1. Weight of 100 ml graduated cylinder = A
2. Bulk volume of the compacted soil = B
3. Weight of cylinder + compacted soil = C
4. Weight of soil sample = C-A= D
5. Bulk density (g/cm³) = D/B

pH

Principle: The pH of sample is measured with a pH meter, in which the potential of a hydrogen ion indicating electrode (glass electrode) is potentiometrically measured against a calomel saturated reference electrode, which also functions as a salt bridge. Most pH meters now contain a single integrated electrode. The equipment must be calibrated with a standard buffer solution of known pH before measuring the pH of the

soil. As temperature affects pH, the pH meter is set to according to the temperature of the solution (Varley, 1972; Jackson, 1973).

Reagents: Buffer solutions (pH 4.0, 7.0, and 9.2)

Equipment required: A balance, 100 ml beaker, measuring cylinder, glass rod, pH meter and ordinary tissue paper.

Procedure

1. 25 g of the soil was weighed in a 100 ml beaker and make it to 50 ml final volume by adding of distilled water. The mixture was stirred well for at least four times within a 30-minute period to allow the soil and water to reach equilibrium.
2. In the meantime, the pH meter was switched on.
3. Initially the instrument was calibrated with buffer solution of known pH 4, 7.0, and 9.2.
4. The electrodes were washed with distilled water and wiped dry with a tissue paper.
5. Then, the electrode was dipped in the sample and the readings were taken.
6. Finally, the electrodes were washed with distilled water and placed back into a beaker containing 4.00-7.00 pH buffer or 3-4M KCl.

Interpretation

pH	Category	Soil Rating/Recommendation
<6.5	Acidic	Requires liming for reclamation
6.5-8.7	Normal	Optimum for most crops
8.8-9.3	Alkaline	Requires application of organic manures
>9.3	Alkali (Sodic)	Requires gypsum for amelioration

Electrical Conductivity

Principle: A conductivity meter known as “Solu Bridge” is used to measure the electrical conductivity of a soil solution. It is based on the Wheat Stone Bridge principle, in which alternating current is utilized instead of direct current to prevent electrode polarization and electrolysis of the solution. In a branched circuit with the conductance cell having resistance R_x , two fixed resistances R_1 and R_2 and a variable resistance (R_v) are linked. The variable resistance (R_v) is adjusted until no current flows through it and the reading is taken. The resistance or conductance (R_v) is measured [Richards, 1954; Chopra and Kanwar, 1976].

Interpretation

EC (1:2 soil water; $\mu S/m$)	Soil Rating
Below 800	Normal
800 - 1600	Critical for salt sensitive crops
1600 - 2500	Critical for salt tolerant crops
Above 2500	Injurious to all crops

Organic Carbon

Principle: In the presence of concentrated sulphuric acid, a known weight of soil was treated with an excess of standard potassium dichromate solution. The heat of the sulphuric acid gently digests the soil at a low temperature, oxidizing the organic carbon in the soil to CO_2 . The excess potassium dichromate was titrated against a standard solution of ferrous ammonium sulphate in the presence of a diphenylamine indicator and sodium fluoride or phosphoric acid, which distinguishes the

Apparatus and equipment required: Weighing balance, 100 ml beaker, measuring cylinder, glass rod and conductivity meter.

Procedure

1. 25 g of the soil samples was taken in a 100 ml beaker.
2. Added 50 ml distilled water.
3. Intermittent stirring was done with a glass rod for 30 minutes.
4. The samples were left overnight to obtain a clear supernatant.
5. The conductivity of the supernatant liquid was determined with the help of a conductivity meter.

colour due to their flocculating effect. The hue of the suspension varies from violet to blue to vivid green at the terminal point [Walkley and Black, 1934; Jackson, 1973].

Chemicals and reagents used

1. Potassium dichromate solution (1 N $K_2Cr_2O_7$): 49.04 g of analytical grade $K_2Cr_2O_7$ was dissolved in distilled water and the volume was made up to 1 litre.
2. Concentrated sulphuric acid (H_2SO_4).
3. Orthophosphoric Acid (85%) or sodium fluoride (NaF).

4. Diphenylamine indicator: 0.5 g diphenylamine indicator was dissolved in a mixture of 100 ml concentrated sulphuric acid and 20 ml distilled water. This was stored in an amber colour bottle.
 5. Ferrous ammonium sulphate solution [0.5 N, $\text{FeSO}_4(\text{NH}_4)_2\text{SO}_4 \cdot 6\text{H}_2\text{O}$]: 392 g analytical grade ferrous ammonium sulphate was dissolved in distilled water, to which 15 ml concentrated sulphuric acid was added and volume to made up to 2 litres with distilled water.
- Apparatus required:** 250 ml Erlenmeyer (Conical) flask, pipette, burette and measuring cylinder.

Procedure

This process is also known as Walkley and Black's rapid titration method (1934).

1. 2 gm of dried, ground, and sieved soil was taken in a 250 ml conical flask.
2. To it, 10 ml 1 N $\text{K}_2\text{Cr}_2\text{O}_7$ solution was added and shaken gently to mix the contents.
3. Next, 20 ml of concentrated sulphuric acid was added while swirling the flask slowly as the reaction is exothermic and a lot of heat is produced.
4. The flask was kept on a dry tile or asbestos sheet for 30 minutes and left to attain

room temperature.

5. After cooling, about 0.5 g of NaF or 5 ml orthophosphoric acid, 100 ml of distilled water and 10 drops of diphenylamine indicator solution were added. These were shaken vigorously for complete mixing.
6. This was titrated against N/2 ferrous ammonium sulphate solution till the colour changes from violet to bright green through blue.
7. The volume of ferrous ammonium sulphate solution used for titration was noted down every time.
8. A blank titration was carried out without any soil.

Calculations

1. Weight of soil taken (W) = 2 g
2. Vol. of N/2 ferrous ammonium sulphate used for blank titration = X ml
3. Vol. of N/2 ferrous ammonium sulphate used to titrate excess nascent oxygen = Y ml
4. Vol. of 1N $\text{K}_2\text{Cr}_2\text{O}_7$ used for oxidation of organic carbon in soil = $(X-Y)/2$ ml
5. 1 ml of 1N $\text{K}_2\text{Cr}_2\text{O}_7$ = 0.003 g C
6. % Organic Carbon in Soil = $\frac{X-Y}{2} \times 0.003 \times 100 / W$

Interpretation

Organic Carbon (%)	Soil Rating
<0.4	Low
0.4-0.75	Medium
>0.75	High

Available Nitrogen

Principle: An excess of alkaline potassium permanganate is applied to a known weight of soil, extracting a relatively easily oxidizable fraction of organic nitrogen. Ammonia is absorbed in excess of boric acid, forming ammonium borate, which is titrated against standard acid to determine the amount of ammonium absorbed (Subbaiah, 1956).

Chemicals and reagents required

1. Potassium permanganate solution (KMnO_4): 3.2 g/l of potassium permanganate was dissolved in distilled water and the volume was made up to 1 litre.
2. Sodium hydroxide solution (NaOH): 25 g/l of sodium hydroxide pellets were dissolved in distilled water and the volume was made up to 1 litre.
3. 0.02 N sulphuric acid (H_2SO_4).
4. Mixed indicator: 0.066 g of methyl red and 0.099 g of bromocresol green were mixed in 100 ml of ethanol.
5. Boric acid: 25 g/l of boric acid was dissolved in one litre of distilled water and to it 40 ml mixed indicator was added. Then, the pH was adjusted to 4.5-5.0 by adding 2.5 % NaOH .

Apparatus and equipment required: Kjeldahl distillation assembly, measuring cylinder, burette, balance, pipettes, and 100 ml conical flask.

Procedure

1. The Kjeldahl assembly was prepared by dipping the respective inlet tubes, one in

0.32% KMnO_4 and second in 2.5% NaOH reagent tanks.

2. 5 g soil sample was weighed and put into distillation tube carefully so that the soil sample does not stick to the sides of the tubes. Soil particles attached to the sides of the tube were washed down with distilled water.
3. The distillation tube was fixed in distillation unit and the sample was moistened with distilled water by pressing the dilution key.
4. 25 ml of 2.5% boric acid was taken in a conical flask and the receiving end of the distillation tube was dipped in it.
5. Next, 25 ml of KMnO_4 and 25 ml NaOH were added in the sample by pressing the respective keys.
6. The heating unit was switched on, and the process ran for 6 minutes.
7. The ammonia gas released from the sample was distilled and collected into the receiver containing acid. After complete digestion, the receiver flasks were removed.
8. The ammonium borate formed in the receiver flask was titrated against 0.02 N H_2SO_4 acid and note the volume of 0.02 N H_2SO_4 utilized. The colour changes from bluish green to wine red.

Calculations

1. Weight of soil taken = 5 g
2. Vol. of 2.5% boric acid taken = 25 ml
3. Vol. of 0.02 N H_2SO_4 used to titrate ammonium borate = X ml

4. 1 ml of 0.02 N H_2SO_4 = 0.00028 g of N
5. Available N (%) = 0.00028 g of N
6. Available N (ppm) = percentage N $\times$ 10,000
7. Available N (Kg/ha) = ppm $\times$ 2.24

Interpretation

Available Nitrogen (kg/ha)	Soil Rating
<272	Low
272-544	Medium
>544	High

Available Phosphorous

Principle: The activity of Ca^{2+} in the soil solution and the pH of the soil regulates the solubility of calcium phosphate in it. The bicarbonate (HCO_3^-) activity in the soil is increased by the 0.5 M NaHCO_3 solution buffered to pH 8.5, which reduces calcium activity. As a result, some phosphate from the surface of calcium phosphate gets dissolved in the soil. Similarly, due to the inactivation of Al and Fe, NaHCO_3 solution removes some phosphorous from Al and Fe phosphates. The precipitation of phosphate released from calcium phosphate is prevented by low Ca^{2+} activity. The soluble phosphate forms heteropoly complexes with molybdate ion freed from ammonium molybdate solution when added to the soil extract. (Bray and Kurtz, 1945; Black, 1965).

Chemicals and reagents required

1. Standard phosphorous solution
 - i. Standard solution of P (100 ppm): 0.4387 g of KH_2PO_4 was dissolved in distilled water and the volume was made up to 1 litre.
 - ii. Standard solution of P (5 ppm): 5 ml of 100 ppm P solution was diluted to 100 ml with distilled water.

2. 0.5 M NaHCO_3 : 42 g of NaHCO_3 was dissolved in distilled water and the volume was made up to one litre after adjusting the pH to 8.5 with sodium hydroxide using a pH meter.
3. Sulphuric acid (5N): 139 ml of concentrated H_2SO_4 was diluted to 1 litre.
4. Reagent A: Dissolve 12 g of ammonium paramolybdate in 250 ml distilled water. Separately, 0.2908g of potassium antimony tartrate ($\text{KSbO}_3 \cdot \text{C}_4\text{H}_4\text{O}_6$) was dissolved in 100 ml of distilled water. Both these dissolved reagents were added to 1 litre of 5 N sulphuric acid. Both were mixed thoroughly and diluted with distilled water to 2 litres.
5. Reagent B: 1.056 g of L-ascorbic acid was dissolved in 200 ml of reagent A and mixed. It was prepared freshly before use.

Apparatus and equipment required: 100 ml conical flasks, funnels, pipette, (1 and 5 ml), 25 ml volumetric flasks, 100 ml measuring cylinder, electric shaker, Whatman No. 1 filter paper and spectrophotometer.

Procedure

a) Preparation of a standard curve

The relationship between the intensity of the coloured solution of a substance and

the percent transmittance or absorbance of the light rays flowing through the solution was depicted by a standard curve. It was used to figure out how much of a certain element is present in an unknown sample. 0, 0.5, 1, 2, 3, 4, 5 ml of P solution was taken in seven different 25 ml volumetric flasks to make the standard curve. It will produce a solution with a final concentration of 0, 0.1, 0.2, 0.4, 0.6, 0.8 and 0.1 ppm, respectively. To it, 5 ml of extracting solution and 0.5 ml 5N H_2SO_4 were mixed and shaken well until the evolution of CO_2 stopped. 10ml of distilled water was added while washing the neck of the flask and 4 ml of reagent B and the volume was made up to the mark with distilled water and mixed. All flasks developed a blue colour of variable intensity. The intensity of blue colour was read on spectrophotometer at 880 nm. A standard curve was plotted using P concentration against absorbance value to establish their relationship.

b) Analysis of the test sample

- 1) 1 g of soil sample was taken in a 100 ml flask.
- 2) To it, a pinch of Darco-G 60 and 20 ml of 0.5 N NaHCO_3 solution were added.
- 3) The flask was placed on an electric

shaker and mixed at a constant speed for half an hour. Then the contents were filtered through Whatman No. 1.

- 4) A blank was prepared by following all the steps without addition of soil.
- 5) In case, the filtrate was not clear, a pinch of Darco – G was added.
- 6) 5 ml of the filtrate was taken in a 25 ml volumetric flask and proceed further for colour development as described under preparation of standard curve.

Calculations

1. Weight of soil sample taken = 1 g
2. Vol. of 0.5N NaHCO_3 solution added = 20 ml
3. First dilution = 20 times
4. Vol. of the filter taken for colour development = 5 ml
5. First volume made = 25 ml
6. Second volume = 5 times
7. Total dilution = $20 \times 5 = 100$ times
8. Concentration of P from spectrophotometer = X AU (absorbance units)
9. Available P in soil (ppm) = $X \text{ (AU)} \times 100$
10. Available P (Kg/ ha) = $\text{ppm} \times 2.24$

Interpretation

Available Phosphorus (kg/ha)	Soil Rating
>12.4	Low
12.4-22.4	Medium
22.4-50	High
>50	Very High

Available Potassium

Principle: In a neutral normal ammonium acetate solution, a known weight of soil was shaken. Potassium (K) ions absorbed on soil colloids exchange ammonium ions. The amount of exchangeable and water-soluble potassium in the extract was measured using a flame photometer. The transfer of non-exchangeable K to exchangeable form was hampered during ammonium acetate extraction because ammonium ions, like K^+ , retain strongly charged layers together (Black, 1965; Merwin and Peech, 1951; Jackson, 1973).

Chemicals and reagents required

1. Neutral normal ammonium acetate solution (CH_3COONH_4): 77.09 g/l of ammonium acetate was dissolved in distilled water and the volume was made up to 1 litre. The pH of the solution was adjusted to 7 with ammonium solution or acetic acid.
2. Standard solution of K (1000 ppm K): 1.91 g of potassium chloride (KCl) was dissolved in distilled water and the volume was made to 1 litre.
3. Working standard solution of K: The stock solution was diluted 100 times to get 10 ppm K solution.

Apparatus and equipment required: A weighing balance, 150 ml conical flasks, a

shaker, funnels, beaker, Whatman filter paper No 1, pipettes and a flame photometer.

Procedure

1. 5 g of soil was weighed in a 150 ml conical flask.
2. To this, 25 ml of neutral normal ammonium acetate solution was added.
3. The mixture was shaken for 5 minutes on an electric shaker and then filtered through Whatman No. 1 filter paper.
4. 5 ml of the filtered extract was taken in a 25 ml volumetric flask and the volume was made up with distilled water. This solution was fed into the atomizer of the flame photometer and readings were noted down.

The amount of K in the test sample was calculated by using the dilution factor.

Calculations

1. Weight of soil sample taken = 5 g
2. Volume of the neutral normal CH_3COONH_4 solution added = 25 ml
3. Dilution = 5 times
4. Reading of K (ppm) in flame photometer = Y
5. In ppm K = $Y \times \text{total dilution} - A$
6. In kg/ha = $A \times 2.24 - C$

Interpretation

Available Potassium (kg/ha)	Soil Rating
<137	Low
137– 337	Medium
>337	High

Available Sulphur

Principle: Soil was shaken with 0.15 % CaCl_2 solution. During extraction, chloride ions displace adsorbed sulphate while calcium ions decrease soil organic matter extraction and hence, eliminate contamination caused by extractable organic sulphur. The turbidity produced by the precipitation of sulphate as barium sulphate is measured on a spectrophotometer at a wavelength of 420 nm. The turbidity is stabilized using gum acacia solution, which prevents the barium sulphate formed from settling (Lisle et al., 1994).

Chemicals and reagents required

1. Extracting solution (0.15% CaCl_2): 1.986 g of calcium chloride dihydrate ($\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$) was dissolved in distilled water and volume made up to 1 litre.
2. Barium chloride (BaCl_2)
3. Gum acacia solution (0.25%): 0.25 g of gum acacia was dissolved in distilled water and diluted to 100 ml.
4. Standard sulphur solution (100 ppm): 0.5434 g of the reagent grade potassium sulphate (K_2SO_4) was dissolved in distilled water and diluted to 1 litre.

Apparatus and equipment required: 150 ml conical flask, funnel, pipettes, 25 ml volumetric flasks, electric shaker, and spectrophotometer and Whatman No. 42 filter paper.

Procedure

a) Preparation of standard curve

1. 0.25, 0.5, 1.0, 2.5 and 5.0 ml of 100 ppm S solution were taken in different 25 ml volumetric flasks. It was theoretically

calculated to give 0, 1, 2, 4, 7, 10, 20 ppm concentration of sulphur in the final volume.

2. To every flask 10 ml 0.15% CaCl_2 solution and 1 g BaCl_2 were added.
3. Mixed for 1 minute to dissolve all the crystals.
4. Next, 1ml 0.25% solution of gum acacia was added.
5. The volume was made up to the mark for all the flasks and shaken properly for thorough mixing. Within 5-30 minutes after the development of turbidity, the standards were read on a spectrophotometer at 420 nm.
6. 0 absorbance at 0 ppm solution (blank) was adjusted.
7. A standard curve was plotted showing relationship between concentration of S (turbidity) and transmittance/absorbance readings.

b) Analysis of test samples

1. 10 g air dried soil was weighed and transferred to a 150 ml conical flask.
2. 50 ml of 0.15% CaCl_2 solution was added, and the mixture was shaken for 30 minutes on an electric shaker.
3. Filter the suspension through Whatman No. 42 filter paper.
4. 20 ml of the filtrate was taken in a 25 ml volumetric flask and the same steps as in case of standard curve were followed.

5. A blank was run with all the chemicals except the soil.
6. The sulphate concentration of unknown samples was determined from the standard curve.
3. First dilution= 5 times
4. Volume of aliquot taken= 20 ml
5. Final volume= 25 ml
6. Second dilution= 1.25 times
7. Total dilution= $5 \times 1.25 = 6.25$ times
8. ppm of S from standard curve= Y
9. ppm of S in soil= $Y \times 6.25$
10. S in kg/ha= ppm of S $\times 2.24$

Calculations

Interpretation

Available Sulphur (ppm)	Soil Rating
<10 ppm	Deficient
>10 ppm	Sufficient

Heavy Metal

All the heavy metal i.e. Cr, Ni, As, Sr, Cd, Hg and Pb, are extracted with the help of ICP-MS (Make-Thermo Scientific instrument) (Retka et al., 2010).

Procedure

1. Take the sample and homogenize properly.
2. Take approximately 0.1 to 0.2 g sample in microwave vessels and add 4 ml of HNO_3 (Suprapure grade), add 1 ml of H_2O_2 (Suprapure grade).
3. Kept at room temperature 20-30 minutes for open digestion.
4. Afterwards samples were put in microwave for close digestion.
5. After digestion, samples were transferred into the 50 ml volumetric flasks and volume make up to the mark.
6. Samples were vortexed properly and run of ICP-MS against the linearity.

Calculations

Calculate the concentration of the elements as follows.

Sample Conc. = $(\text{Sample reading} - \text{reagent blank reading} \times \text{dilution factor}) / \text{Sample Wt.}$

Micronutrient

Principle: All the four micronutrient cations i.e. Zn, Mn, Fe and Cu, are extracted by shaking the soil with DTPA extracting solution containing 0.005M DTPA, 0.1 M TEA (Triethanol amine) and 0.01 M $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ buffered at pH 7.3. During this extraction, TEA gets protonated as HTEA^+ because of which micronutrient cations from the solid phase comes into solution and are chelated by the DTPA. Buffering of the extractant in the slightly alkaline pH range and inclusion of soluble Ca^{2+} through $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ helps avoiding dissolution of CaCO_3 and thus excludes from the estimation of the occluded micronutrients, which do not

form a part of the pool that is available for absorption by plant roots. After that the contents of the micronutrients cations in the soil extract are estimated on atomic absorption spectrophotometer (Katyal and Sharma, 1991).

Chemicals and reagents required

1. DTPA extraction solution: This solution was prepared to contain 0.005M DTPA, 0.01M CaCl_2 and 0.1M TEA [Triethanolamine] and its pH was adjusted to 7.3. For preparing one litre of this solution, 13.3 ml $(\text{HOCH}_2\text{CH}_2)_3\text{N}$ i.e. TEA, 1.967 g DTPA and 1.47 g $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ were dissolved in about 500 ml of deionized water. Sufficient time was given for DTPA to dissolve, and the contents are diluted to approximately 900 ml. The pH of the solution was then adjusted to 7.30 ± 0.05 by adding 6N HCL while stirring and finally the contents were diluted to 1 litre. This solution was stable for several months.

Apparatus and equipment required: 1 litre volumetric flask, 100 ml narrow mouth

polyethylene bottles, pipettes, electric shaker, Whatman No. 1 filter paper and atomic absorption spectrophotometer.

Procedure

1. 12.5 g of air-dried soil sample was taken and transferred to a 100 ml narrow mouth polyethylene bottle.
2. 50 ml DTPA solution was added, and the bottle was closed with the stopper.
3. The bottle was shaken on an electric shaker for 2 hours at 25°C .
4. The contents were then filtered through Whatman No. 42 filter paper to obtain a clear solution.
5. Also, a blank was run with only DTPA solution without the soil.

Calculations

1. Weight of soil used for extraction = 12.5 g
2. Volume of the extractant used = 50 ml
3. Dilution = 2 times
4. Concentration of the given micronutrient in extract = A mg/kg
5. Available micronutrient in given soil sample = $A \times 2$ mg/kg

Interpretation

Content below which the soil is deficient	
Metal	mg/kg soil
Zn	0.6
Cu	0.2
Fe	4.5
Mn	3.5

Rhizosphere Soil Microbiology

Principle: The principle for the analysis of microbe's different media is used such as nutrient agar, Eosin methylene blue, MacConkey agar, Azotobacter, Azospirillum, Rhizobium, zinc solubilising, phosphate solubilising and potash mobilizer. The microbial count is usually expressed in CFU (colony-forming units) per gram or millilitre. The direct count method for enumerating bacteria in natural environments is widely used [Kirchman, 1982].

Procedure

- Different growth medium is used to grow different types of microorganisms is given in Table 3.
- The medium is sterilized in an autoclave.
- Petri dishes are used to hold the growth media.
- A small number of bacteria is needed to inoculate the growth media.
- A 100 µl culture of sample is picked up with the help of pipette and transferred to the growth media and spread with the help of L-shaped spreaders.
- The inoculated growth media is incubated at the optimal temperature and conditions for the bacteria to grow.
- After incubation, the bacterial growth can be observed by looking closely at the colonial growth on the surface of a solid medium.

Table 3 Lists the various growth media that are used to cultivate the various kinds of microorganisms

Serial No.	Target Organism	Synthetic Media Used	Make
1.	Total Bacterial Count	Nutrient Broth	HiMedia (M002-500G)
2.	Total Fecal Count	MacConkey Agar	HiMedia (M008S-500G)
3.	Total Coliform Count	Eosin methylene Agar	HiMedia (M317-500G)
4.	Potash Mobilizer	Aleksandrow	HiMedia (M1997-500G)
5.	Zinc Solubilizer	Zinc sulphate	HiMedia (M2023-500G)
6.	<i>Rhizobium</i>	Rhizobium	HiMedia (M408-500G)
7.	<i>Azotobacter</i>	Azotobacter	HiMedia (M1944-500G)
8.	<i>Azospirillum</i>	Azospirillum + KOH	HiMedia (M1720-500G + M1720-500G)
9.	Phosphate Solubilizes	Pikovskaya	HiMedia (GM1719-500G)

Apparatus and equipment required: Weighing balance, spatula, distilled water, measuring cylinder, and a 1000 ml conical flask.

Calculation

1. Colony forming Units (CFU/ml) = Number of colonies × Dilution factor

2. Volume of culture

Correlation Studies and Statistical Analysis

The tests have been performed in triplicates and the mean of values along with the

standard deviation has been represented graphically. A total of 8 parameters have been studied for 26 sites and each parameter has shown considerable variation. The effect of one parameter on the other may be studied through correlation. A correlation coefficient is an indicator of the relationship between two variables. The correlation coefficient is a statistical measure that indicates the strength and direction of the relationship between two variables. Its value ranges from -1 to +1, representing different degrees and types of

correlation. When the correlation coefficient is closer to +1, it signifies a strong positive relationship between the variables. This means that as one variable increases, the other tends to increase as well. A correlation coefficient around 0 implies no linear relationship between the variables. Changes in one variable do not predict or affect changes in the other. As the correlation coefficient approaches -1, it denotes a strong negative relationship. This suggests that as one variable increases, the other tends to decrease.

Results and Discussion

Physicochemical Characterization of Soil

Moisture content is one of the most essential index qualities for determining the relationship between soil behaviour and index values. Soil moisture content expresses the phase

relationships of water, air, and solids in each volume or weight of material. The consistency of a specific soil, combined with its liquid and plastic limitations, is used to represent its relative consistency in cohesive soil (Hossain et al., 2022). The moisture content of different sampling sites is shown in Fig. 1

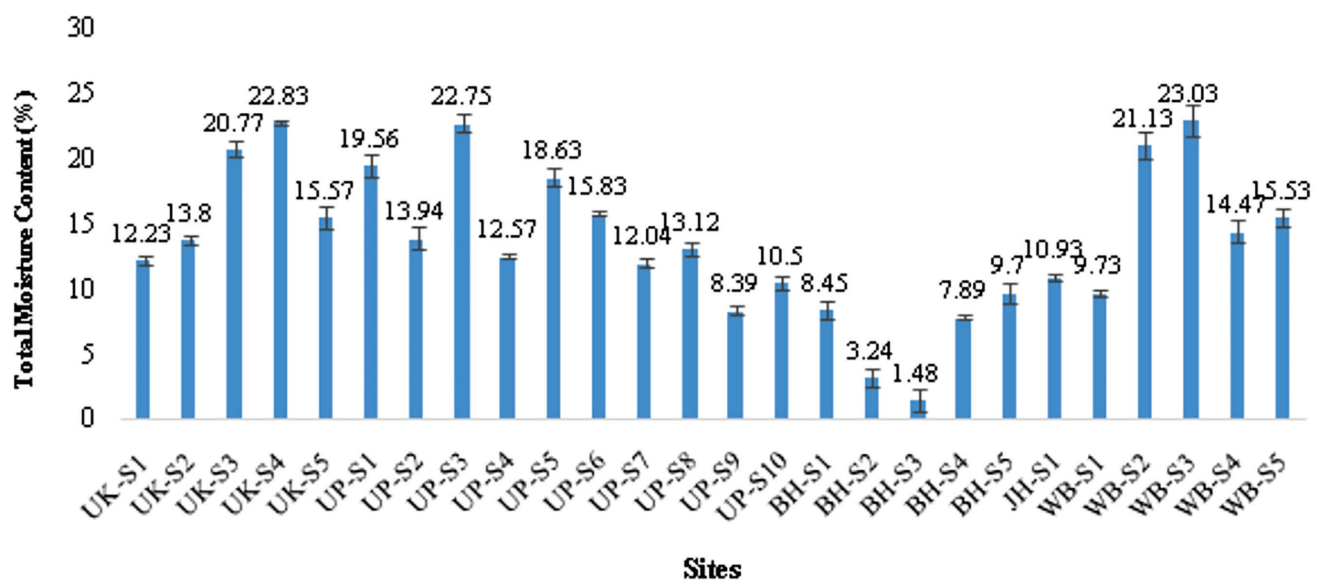


Fig. 1 Total moisture content of different sampling sites

The TMC% was found to be in the range of $1.48 \pm 0.94\%$ (lowest) to $23.03 \pm 1.25\%$ (highest). Soil sample from BH-S3 had very little moisture content i.e., $1.48\% \pm 0.94$. Seven of the soil samples had moisture content below 10%, while in most samples, moisture content was found to be within 20%. Sample from five sites had their TMC% over 20%.

Soil bulk density was another characteristic investigated. It is a measure of how thick or

firmly packed the soil is. The composition of the soil, the structure of the soil ped, the distribution of sand, silt, and clay particles, the volume of pore space, and how densely the particles are packed all influence soil bulk density. Bulk density indicates how easily roots can develop and water can filter through a profile's multiple soil strata (The Globe Program). The soil bulk density of different sampling sites is illustrated in Fig. 2

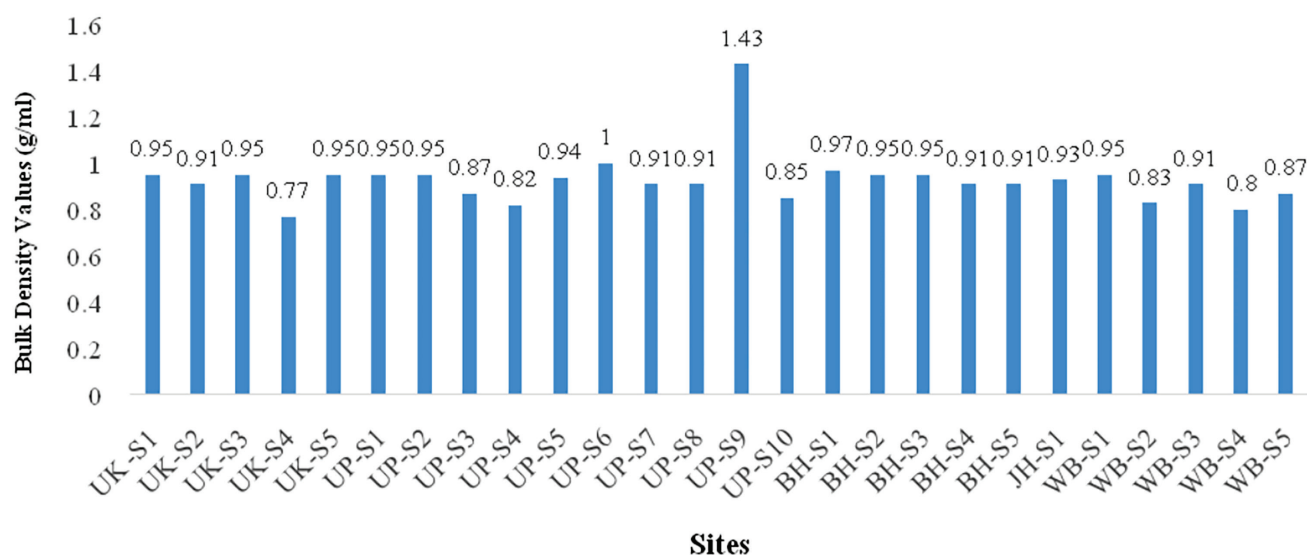


Fig. 2 Soil bulk density of different sampling sites

From the above data, it was deduced that soil bulk density ranged from 0.77 g/ml to 1.43 g/ml. Soil bulk density of UP-S9 was highest i.e. 1.43 g/ml but that of UK-S4 was lowest i.e. 0.77 g/ml. Six of the sites had their bulk density below 0.90 g/ml while the remaining sites had their bulk density values above 0.90 g/ml.

The pH of soil is an important physical attribute that determines species richness

and density (Gough et al., 2000). This happens as soil pH determines the amount of nutrients that are soluble in soil water and their availability to plants. Some nutrients are more available under acidic conditions while some are available under alkaline condition. However, extreme condition of acidity or alkalinity are harmful for the soil as well as plant growth. The pH of the different sampling sites is shown in Fig. 3

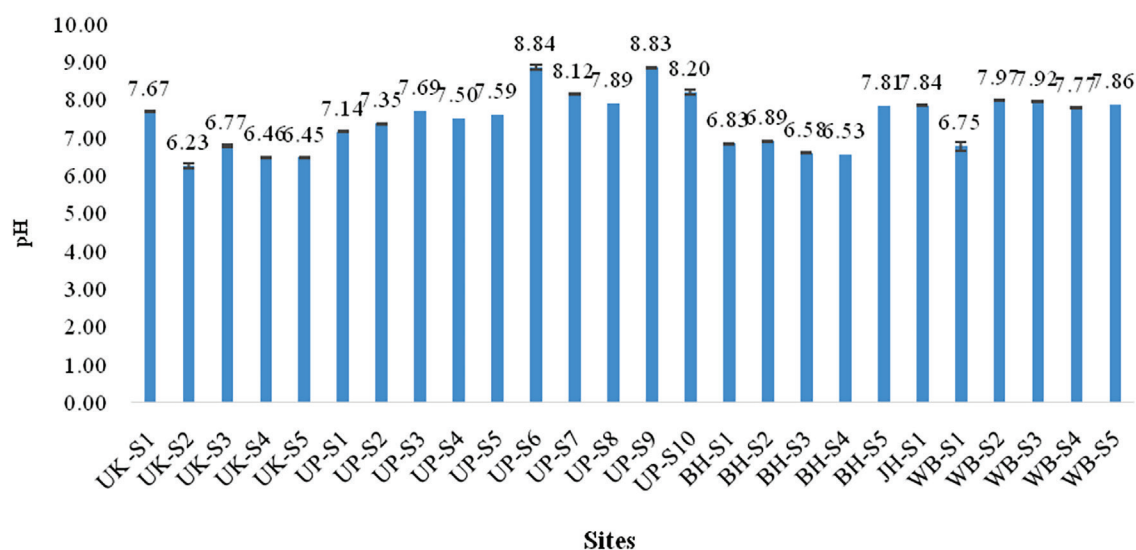


Fig. 3 Soil pH of different sampling sites

The pH of the sample sites ranged from as low as 6.23 ± 0.06 to as high as 8.84 ± 0.01 . Soil samples from UK-S2, UK-S4 and UK-S5 were found to be acidic, with pH levels lower than 6.5. The pH of 9 sites was neutral, whereas the pH of the remaining sites was alkaline.

The next parameter studied, was electrical conductivity of the soil. Soil electrical conductivity is an indicator of soil salinity, clay

content and the nutrient concentration in the field (Heiniger et al., 2003). As shown above, electrical conductivity may be categorized in different divisions and that may be used to determine the salinity of the soil so that which crop could be sown may be decided. The electrical conductivity of soils from different sampling sites was determined and is represented in Fig. 4

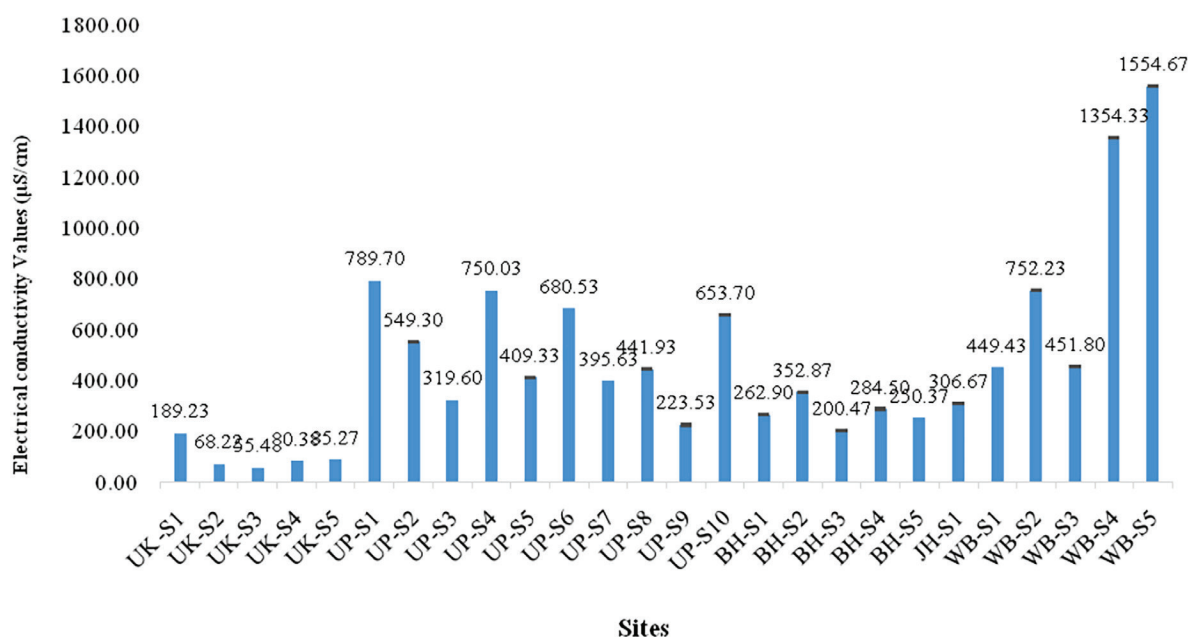


Fig. 4 Soil electrical conductivity at different sampling sites

The electrical conductivity of almost all the soil samples were within the prescribed limits of having EC below $800\mu\text{S}/\text{cm}$. Soil samples from WB-S4 and WB-S5 showed the highest electrical conductivity value of $1354.33\pm 2.52\mu\text{S}/\text{cm}$ and $1554.67\pm 2.52\mu\text{S}/\text{cm}$ respectively. Thus, it may be said that the soil electrical conductivity was within the range at remaining all sampling sites and hence favourable for plant growth.

Soil organic carbon is a measure of the organic content present in soils. It is an important determinant of the hydraulic properties of soil like porosity, water retention and hydraulic conductivity. Thus overall, it is an important parameter determining food content in soil for uptake by plants (Allison, 1965; Rawls et al., 2004). The organic carbon content as measured for the 26 soil samples is shown in Fig. 5.

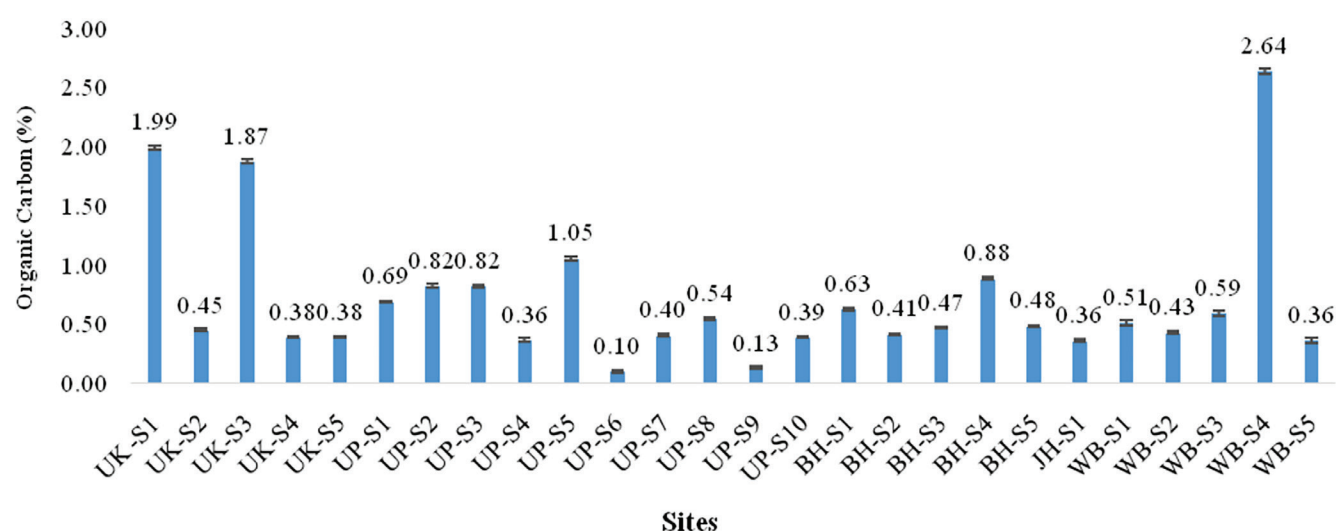


Fig. 5 Soil organic carbon content at different sites

According to the data, the organic carbon content of soil ranged from $0.10\pm 0.01\%$ to $2.64\pm 0.03\%$. UP-S6, which had the highest pH value of 8.84 ± 0.01 had the lowest organic carbon content of $0.10\pm 0.01\%$. The highest quantity of organic carbon content was discovered in WB-S4 ($2.64\pm 0.03\%$), which had an alkaline pH (7.77 ± 0.02). Soil samples from 8 different sites showed low organic carbon concentration, whereas soil samples from 11 different sites had medium organic carbon content. A total of 7 sites had high levels of organic carbon.

The next soil parameter studied was available nitrogen content. Nitrogen is the most important plant macronutrient, and its proper availability is a crucial determinant for plant growth and its optimal health. Researchers (Baričević and Zupančič, 2002) showed that increasing concentration of N added to soil resulted in increased concentration of alkaloids which is a critical component in extracts of medicinal plants. The available nitrogen content in soils from the different sites is shown in Fig. 6.

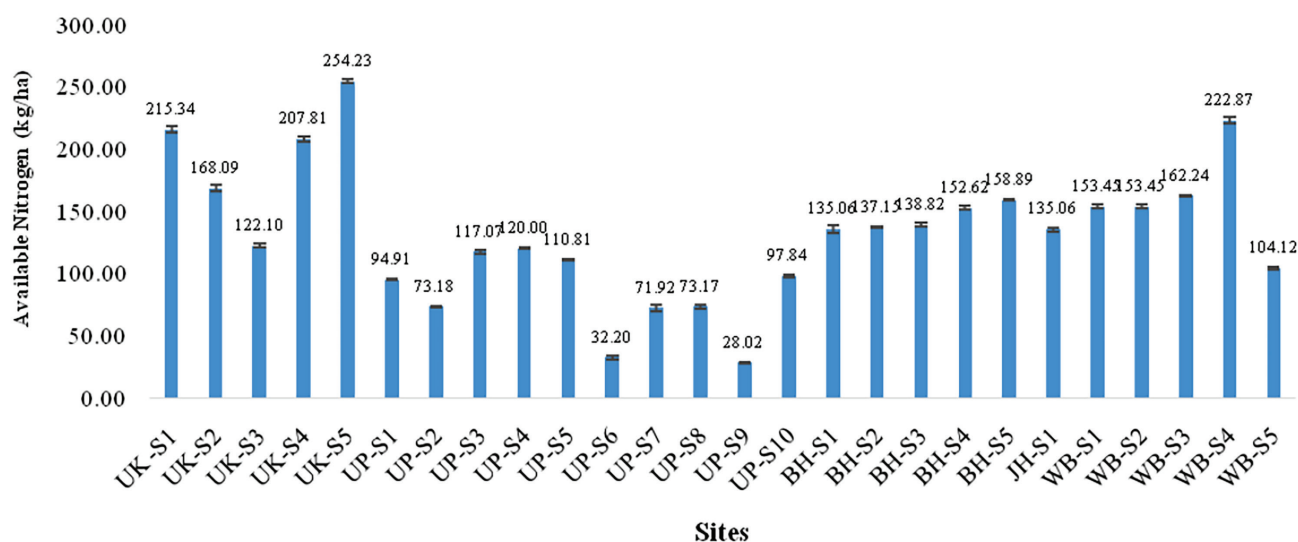


Fig. 6 Soil available nitrogen content at different sites

From the available data it was observed that site UK-S5 had the maximum available nitrogen content (254.23 ± 1.45 kg/ha) and as per soil categories the content was low. For all the other types of soil, the available nitrogen content was low. This could be because all these samples were randomly picked from different sites, which necessarily did not receive any fertilization.

The next parameter tested was that of phosphorous which is another important

plant macronutrient. Phosphorous is a macronutrient that controls the water use efficiency, winter hardiness and promotes root formation (Chakraborty and Prasad, 2021). In case of medicinal plants enough phosphorous in soils promotes development of leaf biomass which is the main part of the medicinal plant in most cases (Stewart, 2003). The concentration of available phosphorous in soils from the different sites is shown in Fig. 7.

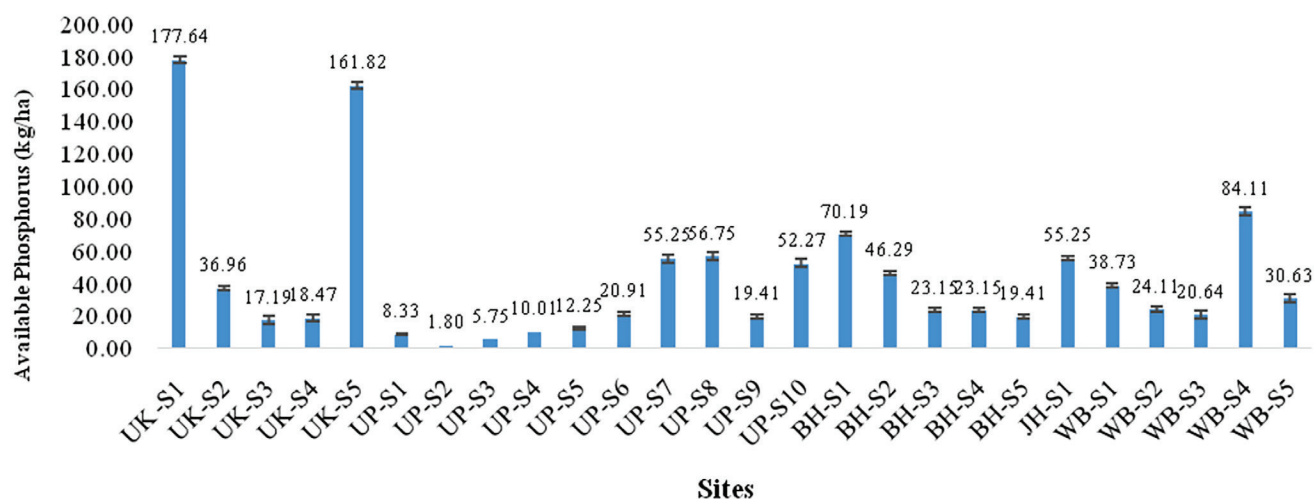


Fig. 7 Soil available phosphorus content at different sites

As per the data, obtained and divisions demarcating phosphorous content in soil, the maximum P was recorded in site UK-S1 (177.64 ± 1.83 kg/ha) while a very less amount was recorded in site UP-S2 (1.80 ± 0.06 kg/ha). The remaining sites have enough amount of the P in soil. Four of the sites had available phosphorus content in low range, while 6 sites were having available phosphorus in medium range. Similarly, 4 sites had their range in high category and the remaining sites had available phosphorus in very high category.

The next parameter is the third major macronutrient for plants, potassium. In general, potassium plays a critical role in the closing and opening of stomata and thus regulates the uptake of water by plants. It also regulates plant growth and yield (Perrenoud, 1977). Literature also suggests that proper potassium content in soil results in higher concentration of essential oils in medicinal plants. Thus, such plants when grown in properly fertilized soil will result in good quality of medicinal plants for maximum benefit of consumers. The potassium content of the different soil samples is shown in Fig. 8.

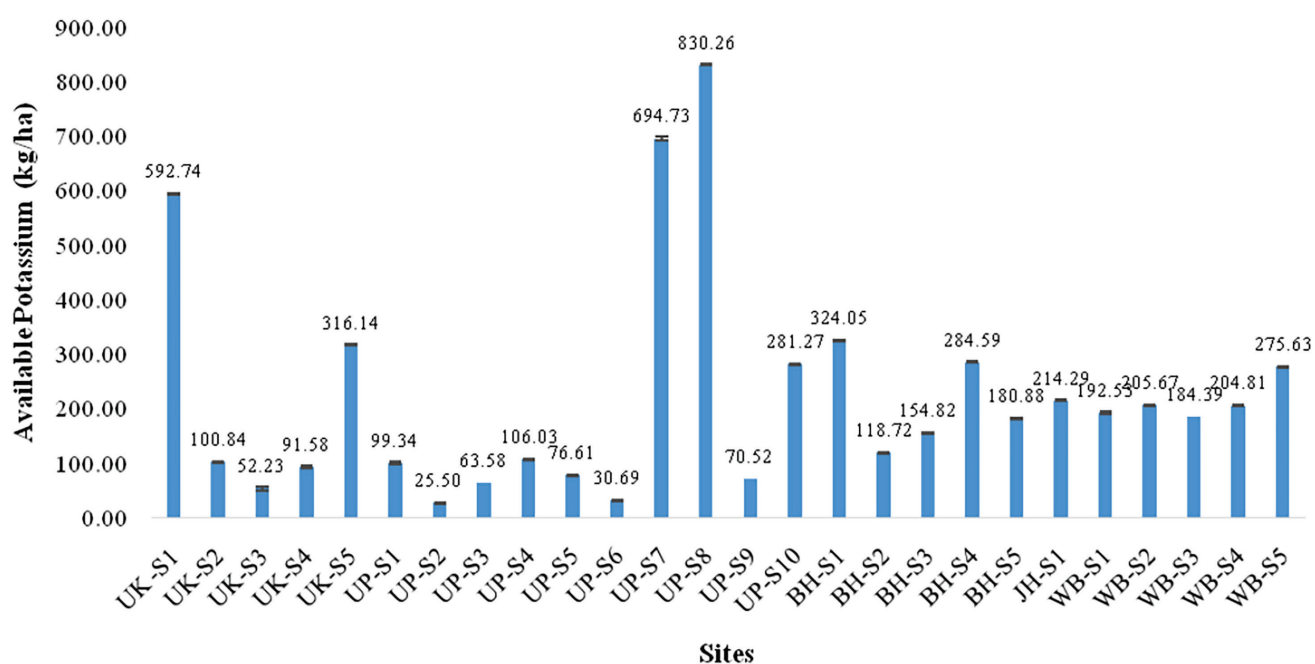


Fig. 8 Soil available potassium content at different sites

From the obtained results, it was seen that site UK-S1, UP-S7 and UP-S8 had high potassium content. As per the divisions of potassium content in soil, the potassium content was medium at twelve sites. The remaining sites had low potassium content.

Sulphur content in soil plays a role as it is up taken by plants for the formation of sulphur containing amino acids and hence the buildup of proteins, chlorophyll, and oils (Tabatabai, 1984). The sulphur content in the soil is shown in Fig. 9.

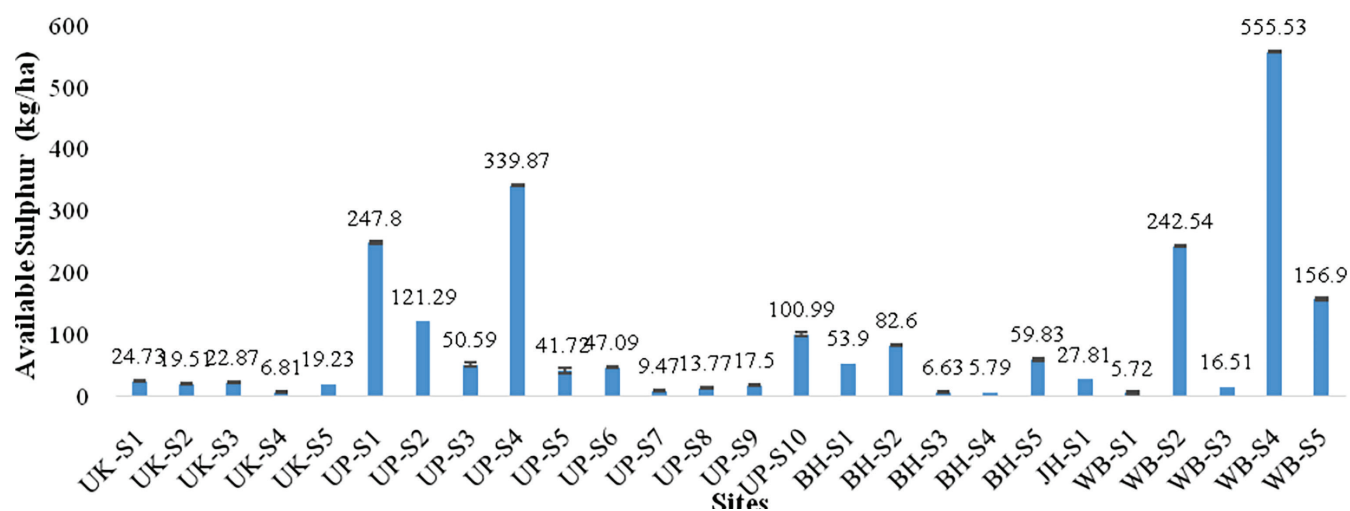


Fig. 9 Soil available sulphur content at different sites

For the results obtained for the sulphur content, it was found that 10 sites were sulphur deficient. The remaining sites had enough sulphur in their soil. Further, correlation studies will help us to understand the effect of pH, EC, or even microbial parameters on sulphur content and vice versa. Additionally, the impact of both high and low sulphur on the composition of phytochemicals can be examined.

Fig. 10 a-g shows the different heavy metals content in all the sampling sites. The concentration of 7 heavy metals Cr, Ni, As, Sr, Cd, Hg and Pb were determined using ICP-MS. Their concentration further determines the level of pollution and contamination in the soil sampling sites.

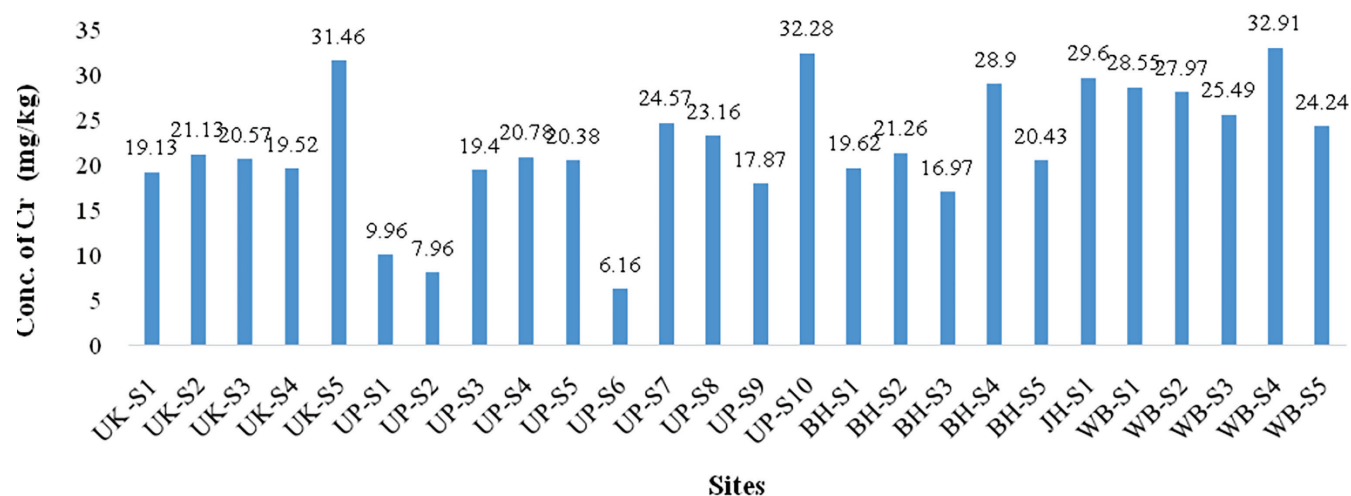


Fig. 10a Concentration of chromium at different sites

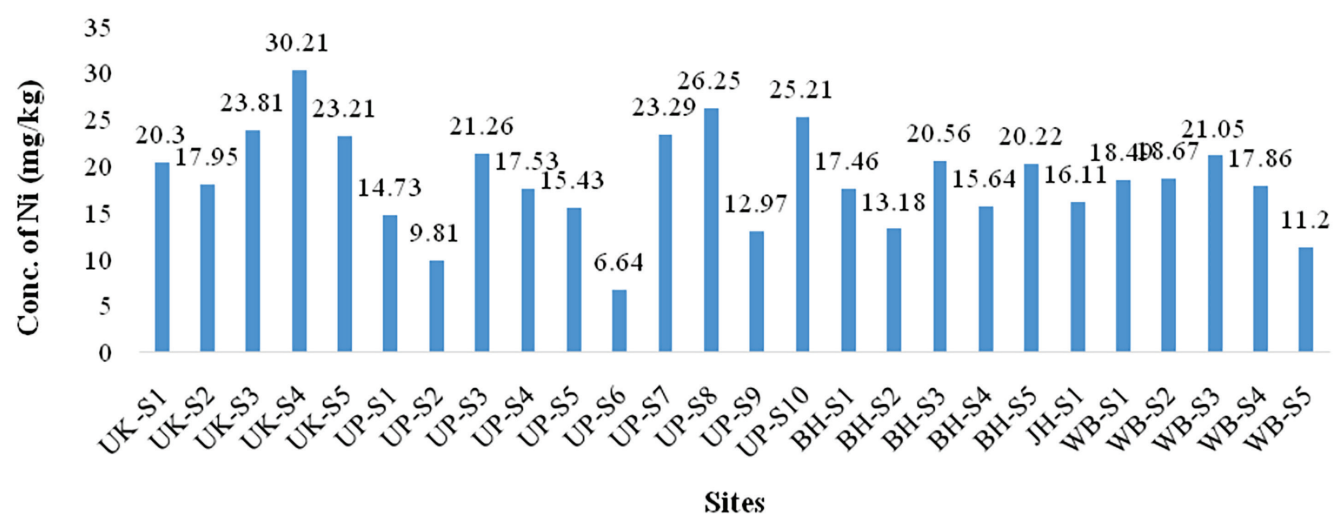


Fig. 10b Concentration of nickel at different sites



Fig. 10c Concentration of arsenic at different sites

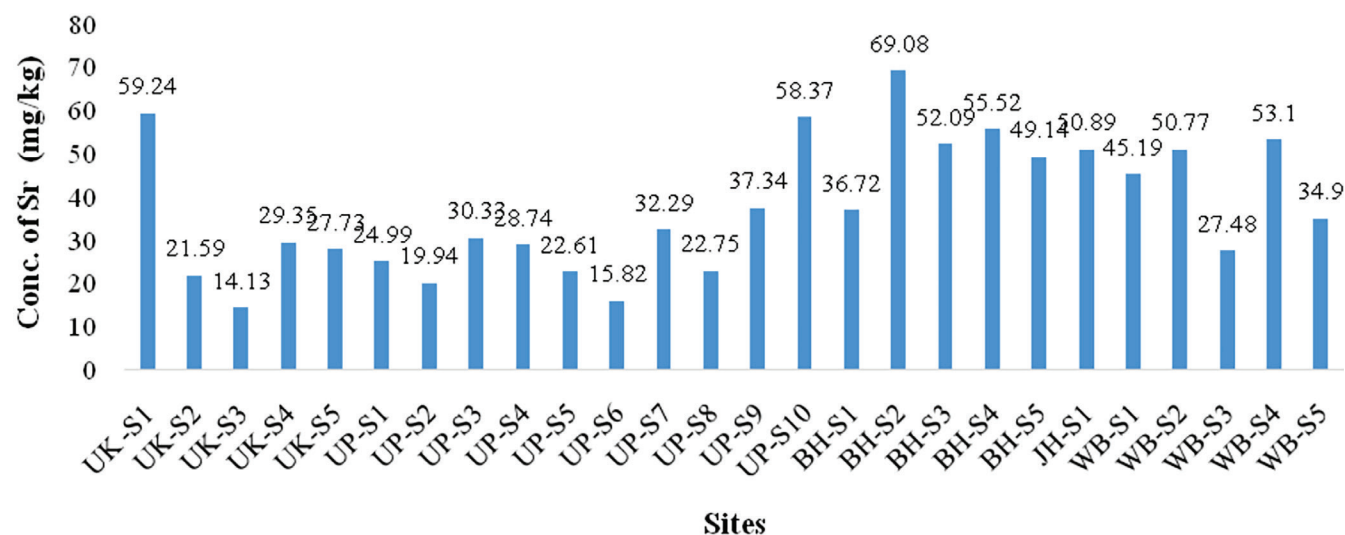


Fig. 10d Concentration of strontium at different sites

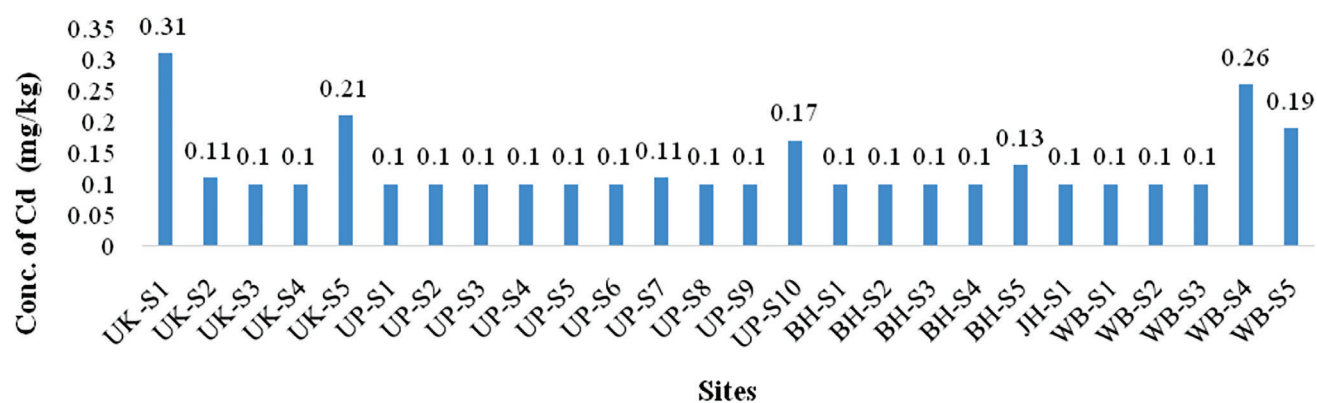


Fig. 10e Concentration of cadmium at different sites

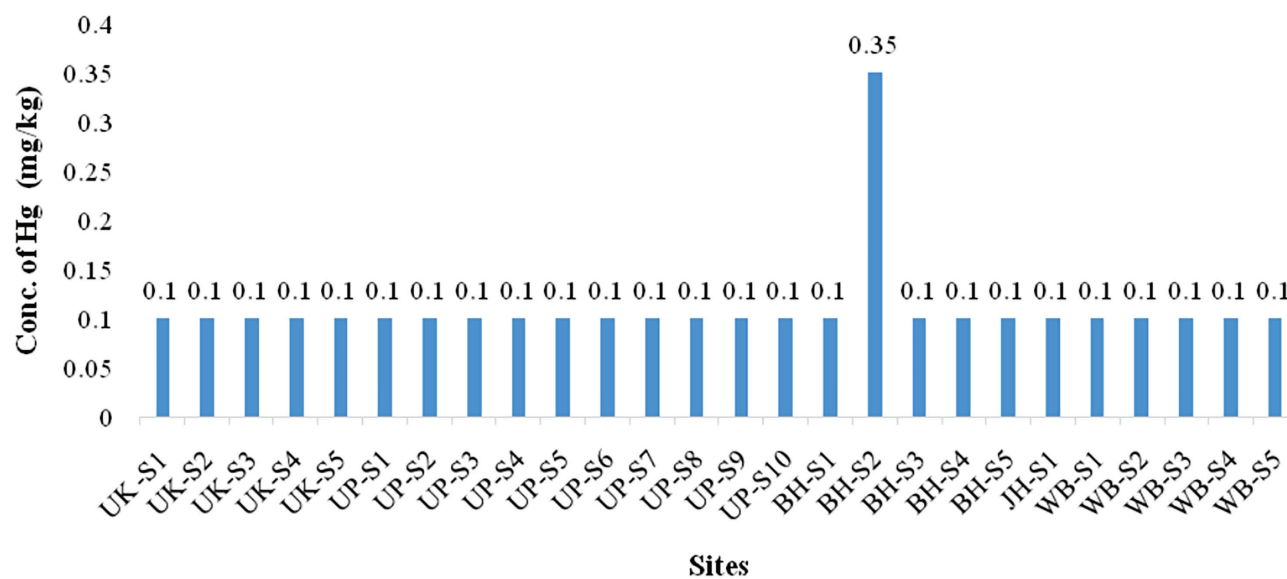


Fig. 10f Concentration of mercury at different sites

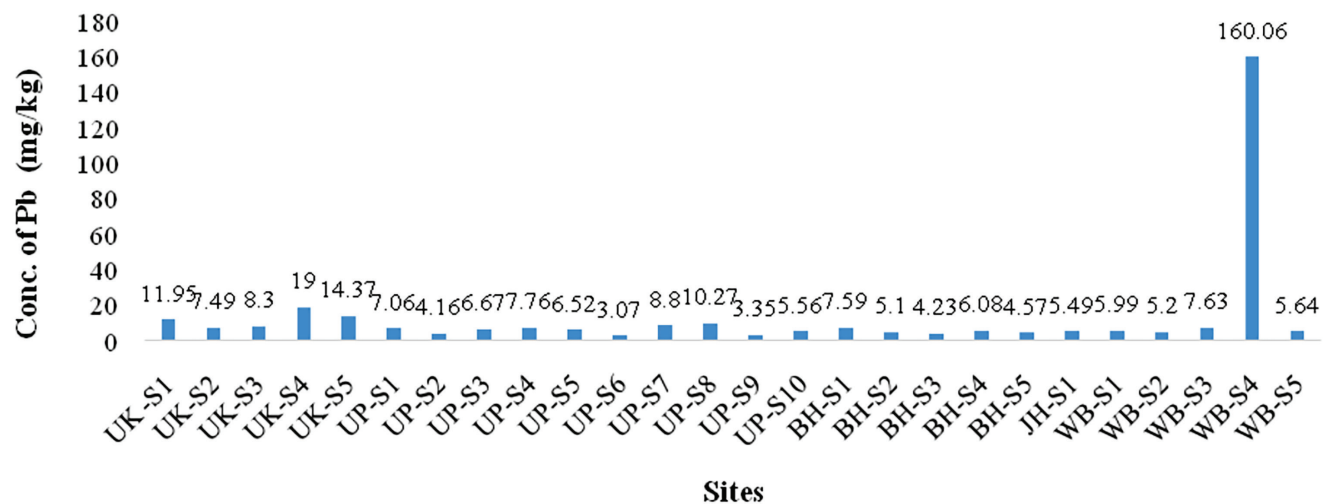


Fig. 10g Concentration of lead at different sites

Micronutrients are elements which are required by plants in very small quantities. They mainly act as co-factor of enzymes. When available to plants in the right quantity, they help in proper metabolism and bring about optimal plant growth and yield. The

concentration of the four micronutrients Zn, Fe, Mn and Cu were determined using atomic absorption spectrophotometer. The values obtained for all the sites are represented in Fig. 11 a, b, c and d.

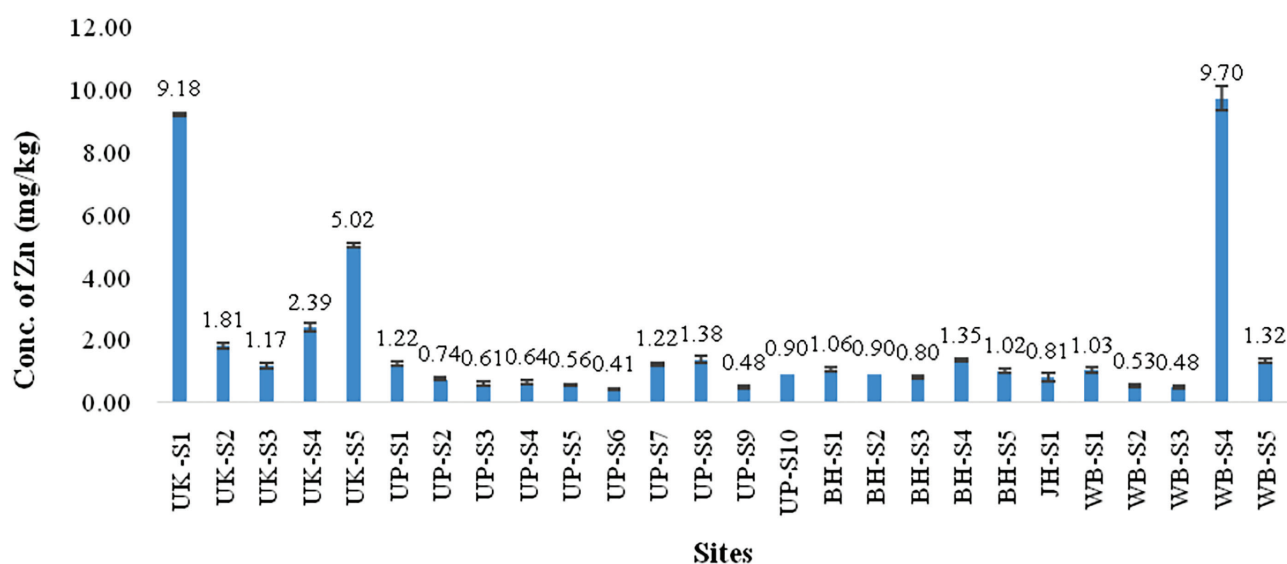


Fig. 11a Concentration of zinc at different sites

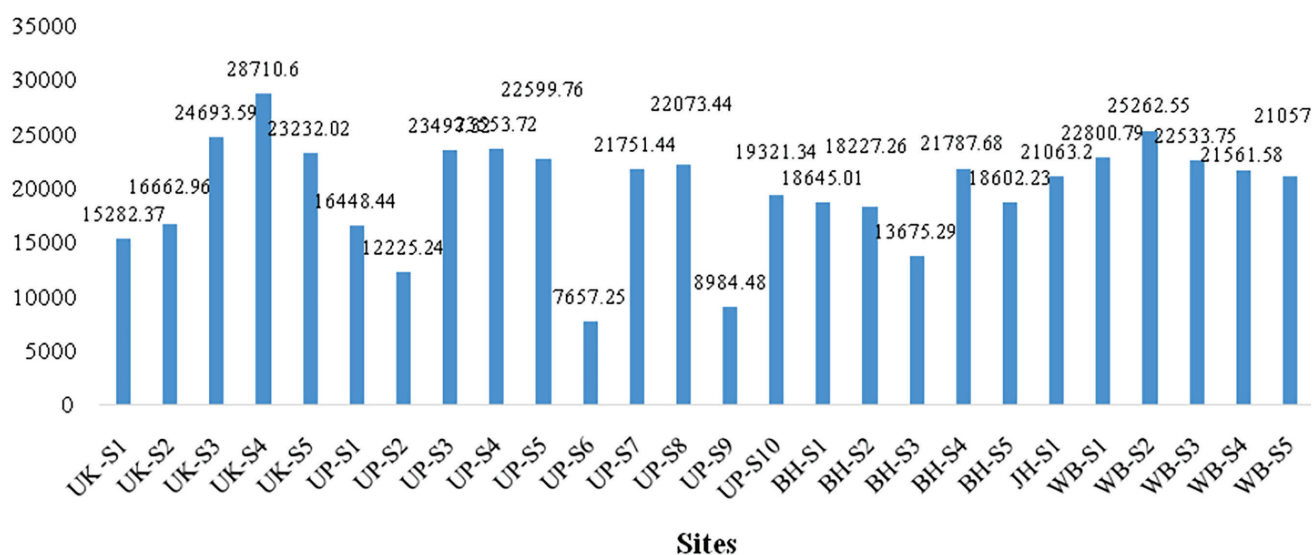


Fig. 11b Concentration of iron at different sites

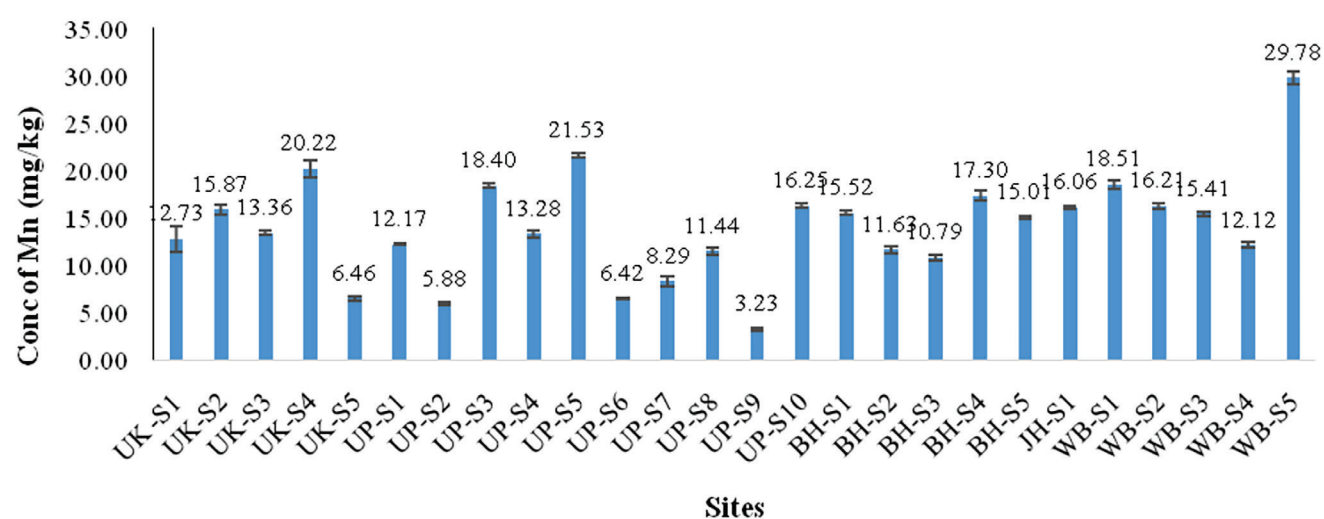


Fig. 11c Concentration of manganese at different sites

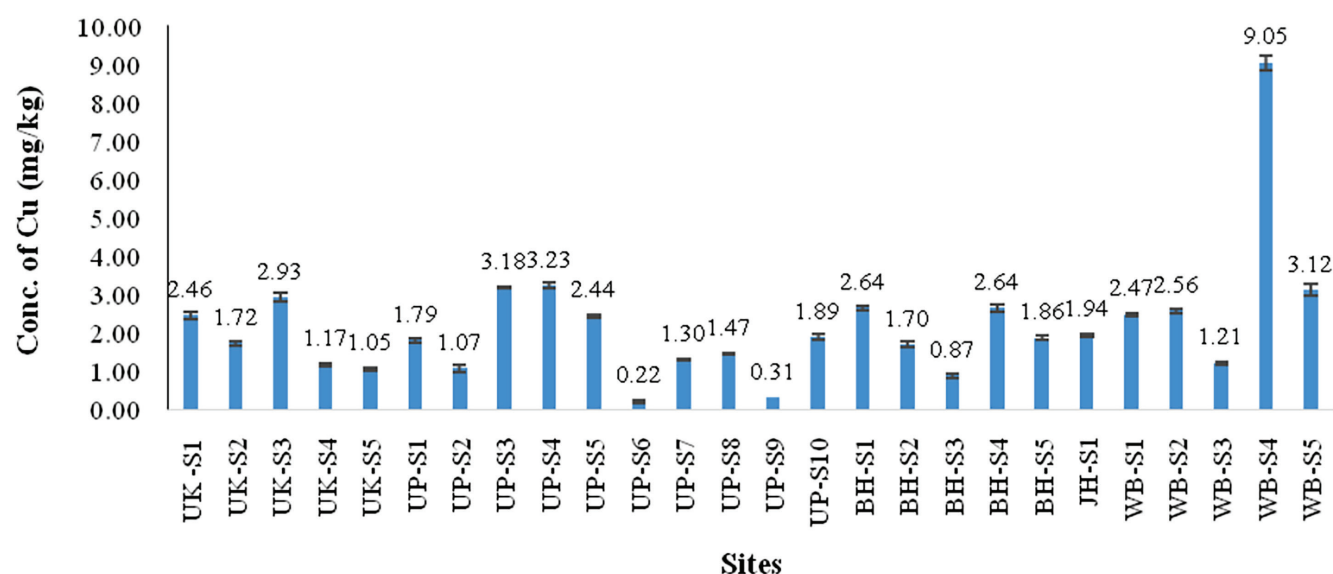


Fig. 11d Concentration of copper at different sites

As per the requirement of micronutrients by plants, there are different prescribed limits. The minimum amount of a particular micronutrient to be present in the soil is considered as the threshold. Deficient soils are those with concentrations below them, whereas sufficient soils have concentrations above them.

Though micronutrients are required by plants in very small quantities, they are

important for proper metabolic functioning. Soils where micronutrients are present in insufficient quantities will result in plant having inadequate metabolism and hence, less of phytochemical content too. Thus, cultivation of medicinal plants must be done in soils with proper nutritional content (Katyal et al., 1991).

Total and Differential Bacterial Count from Rhizosphere

Rhizosphere microbial testing involves analysing the microbial communities in the

soil, rhizosphere, and roots of plants. The rhizosphere microbial test is performed in different media to calculate the bacterial count for the *Ficus racemosa* L. in different locations shown in Fig. 12

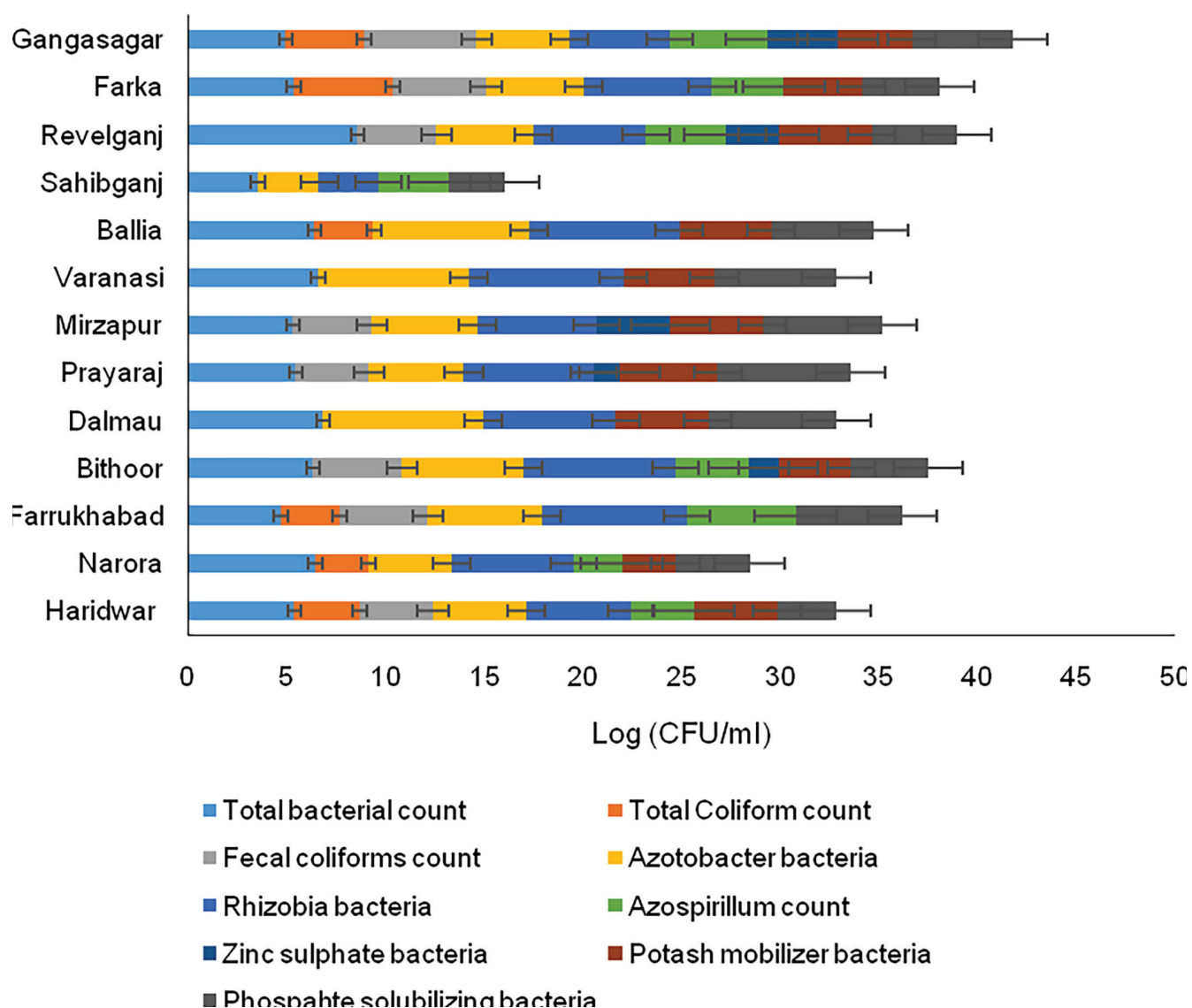


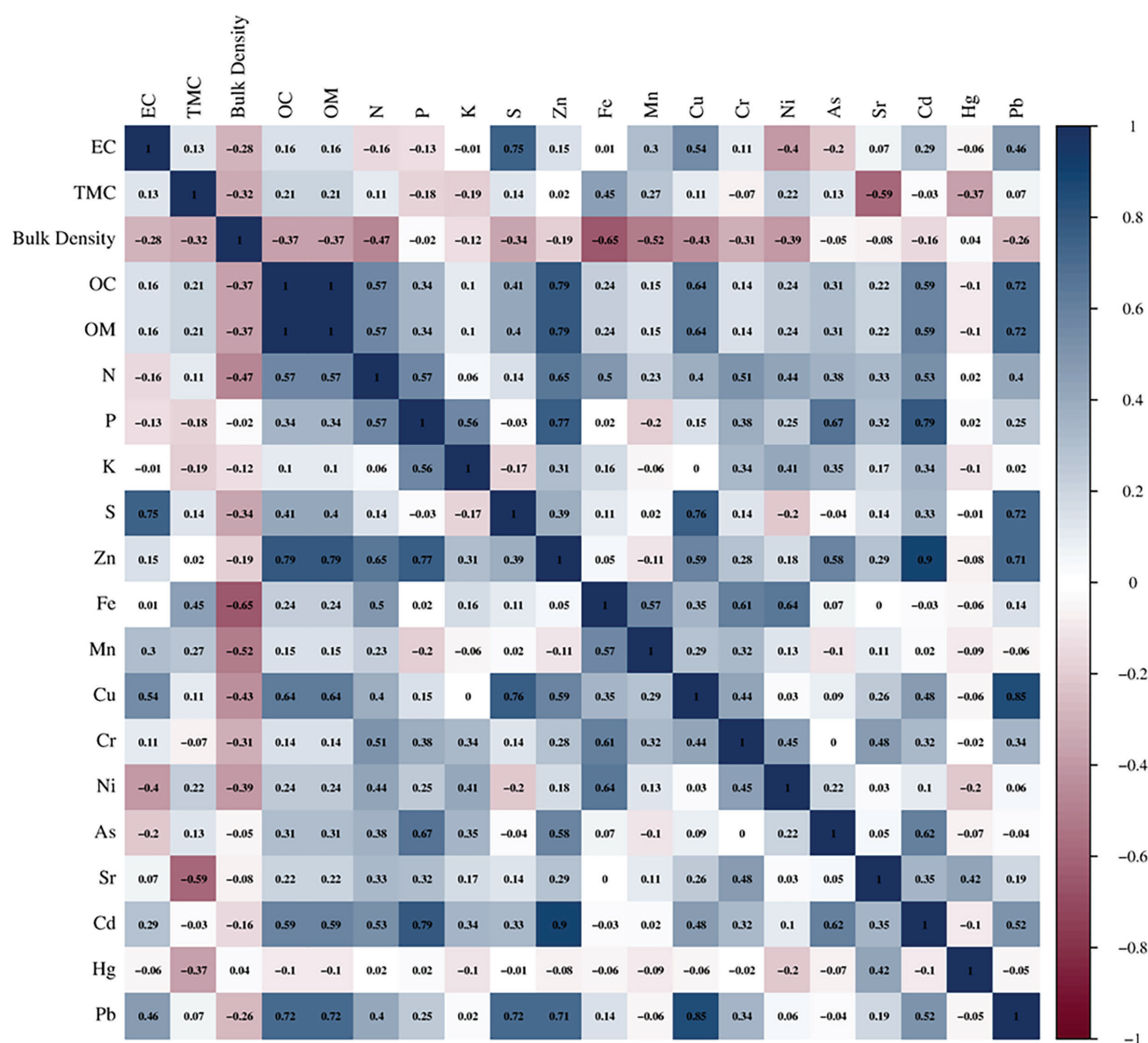
Fig. 12 Total and differential bacterial count

The total rhizosphere microbial test is performed for the identification of total bacterial count which is found highest in Revelganj, recorded 8.602059 cfu/ml and lowest in Farrukhabad is 4.69019 cfu/ml.

Whereas the total faecal and coliform count is highest in Farka and Gangasagar is 5.00432 and 5.69921 cfu/ml The results of correlation studies have been represented as a matrix in Table 4.

Correlation Coefficient Matrix

Table 4 Correlation coefficient matrix



The correlation matrix in Table 6 clearly shows the micronutrient status at different sites and according to the correlation coefficient values of one parameter against the other, the values have been colour coded. The colour coding key also shown above shows the colour codes as per the range of the correlation coefficient

value. According to correlation coefficient values of each parameter against the other, few observations can be made. These are relevant for every parameter from every site because the values were determined using information gathered for every site for every parameter.

- pH showed weak negative correlation with total moisture content, potassium, sulphur, and lead while it showed moderate positive correlation with electrical conductivity.
 - A high degree of strong positive correlation between electrical conductivity and sulphur was observed, while moderate positive correlation was seen between the former and copper and lead.
 - Total moisture content showed moderate positive correlation with iron; furthermore, bulk density showed weak negative correlation with mercury.
 - Organic carbon showed negative correlation with mercury, moderate positive correlation with nitrogen, phosphorus, sulphur and cadmium and strong positive correlation with zinc, copper, and lead.
 - Nitrogen showed a very strong positive correlation with zinc. Phosphorus showed the same with zinc, arsenic, and cadmium.
- Potassium had moderate positive correlation with zinc, chromium, nickel, arsenic, and cadmium.
- A strong positive correlation was seen between sulphur, copper, and cadmium. The same was also observed between zinc, cadmium, and lead. Iron, chromium, and nickel. Manganese and chromium shared moderate positive correlation between each other.
 - Strong positive correlation was seen between copper and lead. Chromium, arsenic, and mercury had negative correlation amongst themselves. The same was also observed between nickel and mercury. A strong positive correlation was seen between arsenic and cadmium.
 - Strontium showed moderate positive correlation between cadmium and mercury. The same was also seen between cadmium and lead. Mercury on the other hand showed negative correlation with lead.

Conclusion

From the physicochemical and microbial analysis of soil, it was found that the parameters were different at each site. If the soil of each site is characterized as per the availability of nutrients and bacteria

according to the recommendations, then the best soil as per the area can be determined. The Table 5 shows the conclusive results of all the results obtained for different parameters from all the sites.

Table 5 Conclusive results for different parameters from all sites

Sites	pH	EC	OC	N	P	K	S	Zn	Fe	Mn	Cu	Cr	Ni	As	Sr	Cd	Hg	Pb
UK-S1	AB	WR	AR	BR	Very AR	AR	WR	WR	WR	WR	WR	WR	WR	AB	WR	WR	WR	WR
UK-S2	BR	WR	WR	BR	AR	BR	BR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
UK-S3	WR	WR	BR	BR	WR	BR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
UK-S4	BR	WR	AR	BR	WR	BR	BR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
UK-S5	BR	WR	BR	BR	Very AR	WR	BR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
UP-S1	WR	WR	WR	BR	BR	BR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
UP-S2	WR	WR	AR	BR	BR	BR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
UP-S3	AB	WR	AR	BR	BR	BR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
UP-S4	WR	WR	BR	BR	BR	BR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
UP-S5	AB	WR	AR	BR	BR	BR	WR	BR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
UP-S6	AB	WR	BR	BR	WR	BR	WR	BR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
UP-S7	AB	WR	WR	BR	Very AR	AR	BR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
UP-S8	AB	WR	WR	BR	Very AR	AR	BR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
UP-S9	AB	WR	BR	BR	WR	BR	BR	BR	WR	BR	WR	WR	WR	WR	WR	WR	WR	WR
UP-S10	AB	WR	BR	BR	Very AR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
BH-S1	WR	WR	WR	BR	Very AR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR

Sites	pH	EC	OC	N	P	K	S	Zn	Fe	Mn	Cu	Cr	Ni	As	Sr	Cd	Hg	Pb
BH-S2	WR	WR	WR	BR	AR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	AB	WR
BH-S3	WR	WR	WR	BR	AR	WR	BR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
BH-S4	WR	WR	AR	BR	AR	WR	BR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
BH-S5	AB	WR	WR	BR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
JH-S1	AB	WR	BR	BR	Very AR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
WB-S1	WR	WR	WR	BR	AR	WR	BR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
WB-S2	AB	WR	WR	BR	AR	WR	WR	BR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
WB-S3	AB	WR	WR	BR	WR	WR	BR	BR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
WB-S4	AB	CSSC	AR	BR	Very AR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR
WB-S5	AB	CSSC	BR	BR	AR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR	WR

The given parameter range is expressed in CSSC (Critical for Salt-Sensitive Crops): This range is vital for salt-sensitive crops. WR (Within Range): The parameter falls within the acceptable range. AR (Above Range): The parameter exceeds the recommended range. BR (Below Range): The parameter is below the recommended range. These parameter ranges are associated with the studies conducted by the Katyal et al., 1991, Hossain et al., 2022, Bowen, 2016, Varley, 1972; Jackson, 1973, Chopra and Kanwar, 1976; Richards, 1954, Jackson, 1973; Walkley and Black, 1934, Subbaiah, 1956, Bray and Kurtz, 1945; Black, 1965, Black, 1965; Merwin and Peech, 1951; Jackson, 1973, Lisle et al., 1994 and Retka et al., 2010.

The comprehensive investigation can also provide a better understanding of how soil quality factors, environmental fluctuations, and altitudinal variations affect the phytochemical composition of medicinal plants.

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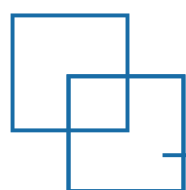
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CHAPTER
04

Traditional and Ethnomedicinal Applications



INTRODUCTION

Plants have also been utilized as a source of medicine in almost all societies from time antiquity. The widespread usage of herbal treatments and healthcare preparations, such as those documented in ancient literature like the *Vedas* and the Bible and derived from frequently used traditional herbs and medicinal plants, may be traced back to the discovery of natural materials having therapeutic characteristics (Hoareau and DaSilva, 1999). In the modern era, the prevalence of illnesses and discomfort has grown. This issue requires researchers to investigate various medicinal herbs to solve this problem (Akerlele, 1993). The use of conventional drugs and herbal remedies as an established norm for maintaining good health has also been frequently recognized in most developing nations (UNESCO, 1996). There is an emerging trend for using medicinal plants in the industrial sector, such as the extraction and production of many medications with illness-curative and biological features (Salehi et al., 2019). Traditional medicine has a long history in India. India's 'Materia Medica' has a wealth of knowledge on folkloric traditions and traditional characteristics of therapeutically useful natural ingredients (Paarakh et al., 2009).

The genus *Ficus* L. is a very significant and vital group of trees that are found in various locations, have various medicinal properties, and play an essential part in various therapeutic objectives (Joseph and Raj, 2010). *F. racemosa* belongs to the Moraceae family and is a large to medium-sized tree. It is also known as 'yajnayoga', 'udumbara', 'goolar', 'dumar', 'bodda', 'heibong', 'jantuphalam', 'dimri', 'yogga dumur', and other names. This plant thrives in the woods or on slopes near a body of water, such as a pond or riverbank (Sasteri, 1992). It is a fast-growing tree that may reach a height of 12 m and thrives in semi-shade, full sun, and damp soil. Its leaves are used in the treatment of diarrhea (World Agroforestry Centre, 2013). Traditionally, the crop has been used for livestock feed, food (both fermented and non-fermented goods), and ceremonial purposes. Each part of this plant (leaves, fruits, bark, latex, and root sap) has medicinal and therapeutic use in Indian traditional medicine for treating piles, dysentery, asthma, gonorrhea, menorrhagia, leukorrhea, hemoptysis, and urinary disorders (Swain and



Downum, 1990). Different researchers have also investigated these different parts for their varied biological functions/activities such as hepatoprotective, chemopreventive, antidiabetic, antipyretic, antitussive, and antidiuretic action (Rao et al., 2002).

Traditional and Ayurvedic Benefits

India is widely recognized for its traditional medical practices, such as Ayurveda, Siddha, and Unani. The ancient Vedas and other literature provide descriptions of medical systems. The Ayurvedic concept emerged and developed in India between 2500 and 500 BC (Subhose et al., 2005). In Ayurveda, 'vata' governs the body's catabolism, 'pitta' controls metabolism, and 'kapha' controls anabolism (Barnes et al., 2004). *F. racemosa* is known by several different names in Ayurveda, including 'gular', cluster fig tree, country fig tree, and 'udumbara' (which is revered by God Dattaguru). In ritual sacrifice, it has also been

employed. Susruta listed the plant's beneficial effects, including astringent, callus-healing in fractures (bhagna sandhaniya), reducing 'rakta pitta', burning feeling, and obesity, as well as being helpful for vaginal diseases (Deep et al., 2013). Various parts of it, including the bark, seeds, fruits, leaves, latex, and roots, are also used medicinally (Usman et al., 2013). It is frequently used as an antioxidant, anti-cancer, anti-bacterial, anti-inflammatory, memory-improving, and gastroprotective drug in Ayurveda, Siddha, Unani, and homeopathic medicinal systems (Pardia et al., 2022) as represented in Table 1.

Table 1 Some important preparations used against various diseases in ancient Ayurveda

S. No.	Diseases/ Conditions	Mode of Administration/Uses	References
1.	Eye disorders	Udumbaraphalamloheghmmmmstanyenadhūpitam. Sājayimśamīcchadairdāhaśūlarāgāśruharṃajit- collyrium prepared from unripe fruits, triturated with cow milk, useful in eye diseases.	Tripathi, 2011
2.	Nasal disorders	Udumbarāṃipakvānigumenamadhunā’pivānighnantināsārattaphamnmāmḍhruvam- ripe fruits along with honey or jaggery, against epistaxis.	Mishra, 2009
3.	Thoracic disorders	bhasmaudumbaram.....kṃaudropetaṃhantilīmhvā’’śuhikkām- bark ash mixed with honey, used for hic-cups	Sharma, 2012

S. No.	Diseases/ Conditions	Mode of Administration/Uses	References
4.	Abdominal disorders	Nyagrodhodumbarāśvatthaśugaṃgānāpothyavāsayet. Ahorātramjaletapteghṃtaṃtenāmbhasāpacet. TadardhaśarkarāyuktaṃlihyātsakṃmaudrapādikaṃAdhovāyadivā'pyūrdhvaṃyasyaraktaṃpravartate- <i>Ghrita</i> (Clarified butter) processed with <i>F. benghalensis</i> (Banyan tree), <i>F. racemosa</i> (Cluster fig tree) and <i>F. religiosa</i> (Peepal tree), infused with sugar and honey, useful in bloody diarrhea and <i>Raktapitta</i> ; Udumbaraśalāṃūnisvinnānījalavāṃpatam. Dadhnāvinīyabhuñjītagrahaṃīglapitonaram- steamed fruits with curd, used in sprue; Nārīstanyenasamṃyuktāṃpibedaudumbarītvacam. Tābhyāṃvāpāyasaṃsid-dhamadyādatyagnīśāntaye- bark paste along with milk, useful in <i>Bhasmaka</i> (polyphagia).	Śāstrī and Chaturvedi, 2011; Bhatta, 2008
5.	Reproductive disorders	Udumbarasyadugdhenamṃkṃtvobhāvitāttilāt. Tailamkvāthenatasyaivasiddhamdhāryam ca pūrvavat- insertion of vaginal suppository prepared from the latex of the plant, <i>Sesamum indicum</i> (Sesame) oil, useful in vaginal disorders; Kṃmaudrayuktaṃphalarasamaudumbarabhavaṃpibet. Asṃgdaravināśāyasaśarkarapayo'nnabhuk- unripe fruit juice mixed with honey, sugar, milk, and rice, useful in metrorrhagia; Udumbarakvāthayutaṃsitāṃhyaṃsugandhiśālīprabhavaṃsitam ca. Yāpiṃmamaśnātinagarbhapātapiṃāmasauvindatijātunārī- rice paste along with the decoction of plant and crystal sugar, used against pain caused due to an abortion; Carma.....udumbarasyavā. Piṃmamtumāmbunāpītamaparāṃpātayekṃmāmāt- bark pounded with rice water, used in afterbirth; Bandākamaudumbaramādareṃavandhyāṃganāpumpaviśuddhivāre. Pūrvamviriktālabhate	Tripathi, 2009; Mishra, 2009; Misra, 2010; Śāstrī and Chaturvedi, 2011; Sharma, 2012a; Sharma, 2012b;
		kumāramchāgasyadugdhenasahaprapītvā- <i>F. racemosa</i> (Cluster fig tree) and <i>Dendrophthoe falcata</i> (Mistletoe) pounded with goat milk and used to promote conception; Palāśodumbaraphalamtilatailasamanvitam. Madhunāyonimālipyagāṃhīkaramamuttamam- topical application of paste prepared from <i>F. racemosa</i> , and <i>Butea monosperma</i> fruits, pounded with honey and <i>Sesamum indicum</i> (Sesame) oil, useful in vaginal disorders.	

S. No.	Diseases/ Conditions	Mode of Administration/Uses	References
6.	Disorder of extremities	Udumbarakṁīrayutamsvaguptāmūlaṁsa-maṁjīmḡimikārasena.Sarāmaṁhamhantya-abāhukākhyamṁnasyaprayogātpurumṁsasarogam- snuff of powder prepared from <i>Mucuna pruriens</i> roots, <i>Lannea coromandelica</i> juice, and <i>Ferula narthex</i> , triturated with <i>F. racemosa</i> latex, recommended in stiffness of arms.	Tripathi, 2012
7.	Dermatological disorders	Jantuphalavalkamadhyamṁkalkikṁtyakila-surabhimūtreṁ.Vidhivadbadhānamgam-bhīrādṁmṁmanāmikāśāntyai- topical application of <i>Ghrita</i> (Clarified butter), fried bark paste of the plant, pounded with cow urine, useful against chronic wounds.	Bhatta, 2008
8.	Generalized body disorders	Pakvodumbarakārśmayapathyākharjūrāgostanām. Madhunāghnantisaṁlīmṁhāraktapittamṁthakpṁthak- juice of the plant, mixed with honey, used in <i>Raktapitta</i> ; Udumbaraphalamṁpimṁvāpibettadrasamevavā- fruits recommended in <i>Raktapitta</i> .	Tiwari, 2007; Sharma, 2012c

Therapeutic Potential

Almost all societies have employed medicinal plants as a source of medicine since the dawn of mankind. The widespread use of herbal medicines and healthcare preparations, such as those mentioned in ancient books like the Vedas and the Bible and made from commonly used traditional herbs and medicinal plants, has been linked to the availability of naturally occurring substances with therapeutic capabilities (Hoareau et al., 1999). Among ancient civilizations, India has long been known as a rich source of natural remedies. The great majority of the medicinal and aromatic plants that are gathered from India's forests are used as raw materials to

make pharmaceutical goods. Since ancient times, these therapeutic plants have also been used for food, spirituality, medicines, and fragrances. Herbal medicine has been used to treat illness since ancient times. In addition to using them to alleviate illness, people revere and hold sacred herbal plants. Numerous myths about sacred plants reveal information about our society and deities. Hindu mythology has connections between all the gods and goddesses and certain plants, trees, and shrubs (Parihar et al., 2021).

F. racemosa is a moderate sized avenue plant of the Moraceae family, sometimes known as the cluster fig tree, Indian fig tree,

or 'goolar' ('gular'). This plant is endemic to Australia, Malaysia, South-East Asia, and India. It thrives in a variety of woodlands and hilly places throughout India, is commonly found near water streams, and is also farmed. Most often found along riverbanks and interior woods from plains to 1500 m in India, Sri Lanka, Pakistan, Queensland, and South China to New Guinea. The plant may be propagated both vegetatively and sexually (through seeds) (Paarakh, 2009; Pingale et al., 2019). Sitosterol, the active ingredient, which is extracted from the stem bark and leaves, has strong anti-diabetic potential. This plant has a wide range of pharmacological properties, including antidiabetic, antioxidant, antidiarrheal, anti-inflammatory, antipyretic, antifungal, antibacterial, hypolipidemic, and antifilarial properties, as well as hepatoprotective properties (Pahari et al., 2022). It is also used to treat a variety of conditions, including hydrophobia, inflammatory glandular enlargement, mumps, diarrhea, pectoral problems, and colon cancer (Joseph et al., 2010; Mohiuddin et al., 2020). Mumps and other inflammatory enlargements are also treated with sap (Pardia et al., 2022). Additionally, the roots are used to cure hydrophobia, pectoral problems, diarrhea, and diabetes. They are also administered to treat mumps and other inflammatory glandular enlargements as well as pectoral complaints and dysentery (Anisuzzaman et al., 2007). Additionally, dysentery, and menorrhagia are all treated with decoction or juice (Yadav et al., 2015;

Chidambaravadivu et al., 2018; Pardia et al., 2022). Additionally, oil-infused root bark is used to treat rheumatism, leprosy, and eczema (Yadav et al., 2015). The root sap is used to treat diabetes, mumps, and gonorrhea (Chopra et al., 1958; Thapa et al., 2001; Chidambaravadivu et al., 2018; Pardia et al., 2022). A decoction of the bark is employed in the treatment of piles, ulcerative colitis, diarrhea, dysentery, asthma, wounds, burns, swelling, swellings of the neck, gonorrhea, scabies, mouthwash for toothaches, urinary tract diseases, uropathy, inflammation, for strengthening gums, anti-hyperglycemic, diabetes, hiccup, and leprosy (Chopra et al., 1958; Anisuzzaman et al., 2007; Nair et al., 2007; Joseph et al., 2010; Urooj et al., 2013). The stem bark can also be applied as a paste or decoction to treat diabetes, leukorrhea, dysentery, diarrhea, and edema caused by burns (Paudyal et al., 2000; Tiwari et al., 2001; Khan et al., 2011). The infusion of bark is used as a treatment for diabetes, diarrhea, menorrhagia, and illnesses characterized by spongy gums (Tiwari et al., 2001). Likewise, the bark and leaves of this plant are valued for their ability to treat a variety of conditions, such as cervical adenitis, spongy gums, menorrhagia, hemoptysis, glandular swelling, abscess, and chronic wounds (Kar et al., 2003; Chidambaravadivu et al., 2018). Burnt bark powder mixed with gingelly oil is used to treat malignant diseases, diabetes, dysentery, ulcerative colitis, and menorrhagia (Chopra et al., 1969; Joseph et al., 2010; Yadav et al., 2015;

Chidambaravadivu et al., 2018). Though, it has several therapeutic characteristics when its bark, leaves, and fruits are combined, including vermicide, astringent, carminative, and antibacterial effects (Kambli et al., 2014; Chidambaravadivu et al., 2018). In addition, leprosy is treated using a bath made from the fruit and bark of the plant (Nadkarni et al., 1976). Diabetes can also be treated using a sap that has been separated from the trunk (Paudyal et al., 2000). To cure bilious infections, it is strongly advised to combine the leaves with honey (Kirtikar and Basu et al., 1975). It is also used to cure wounds, ulcers, piles, boils, blisters, measles, heart disease, bronchitis, wounds, and hair-splitting using the plant's juice, latex, decoction, tea, and wash. (Kar et al., 2003; Joseph et al., 2010; Yadav et al., 2015; Chidambaravadivu et al., 2018; Mohiuddin et al., 2020). Its leaf buds have also been used to treat skin problems (Yadav et al., 1999; Joseph et al., 2010). Cholera, mumps, fractures of the bone, wounds, diarrhea, dysentery, hemorrhoids, stomachaches, diabetes, boils, traumatic swelling, toothaches, vaginal diseases, and discomfort are additional conditions which are treated with the help of its latex. Also, it is boiled with milk and sugar, triggers diarrhea and dysentery and enhances a man's ability (Ghimire et al., 2000; Dangol et al., 2002; Anisuzzaman et al., 2007;

Joseph et al., 2010; Pardia et al., 2022). Its fruits are suggested for conditions such as visceral obstruction, good stomach function, diabetes, weight loss, cholesterol, venereal diseases, urinary calcium loss, macular degeneration, menorrhagia, hemoptysis, constipation, urinary complaints, chronic bronchitis, diseases of the kidney and spleen, dry cough, in voice loss, as a styptic, tonic, leukorrhea, blood disorders and burning sensation and is stomachic and carminative. Additionally, for the treatment of hemoptysis, menorrhagia, and other conditions, the fruits are soaked in milk overnight and used to enhance virility. Its decoction or extract can be used to treat diabetes, leukoderma, menorrhagia, skin irritation, lymphadenitis, sprains, and fibrositis and used as an aphrodisiac. It is also combined with sugar desserts to treat menorrhagia, hemoptysis, and aphthous symptoms. In addition, the fruits are boiled in milk to treat sore throat and visceral blockages (Chopra et al., 1958; Nadkarni et al., 1976; Vihari et al., 1995; Kar et al., 2003; Anisuzzaman et al., 2007; Khan et al., 2011; Singh et al., 2013; Yadav et al., 2015; Chidambaravadivu et al., 2018; Mohiuddin et al., 2020; Pardia et al., 2022). When combined with honey, seed powder is thought to be particularly effective in managing diabetes-related polyuria, thirst, and urine sugar levels as depicted in Fig.1 (Chidambaravadivu et al., 2018).

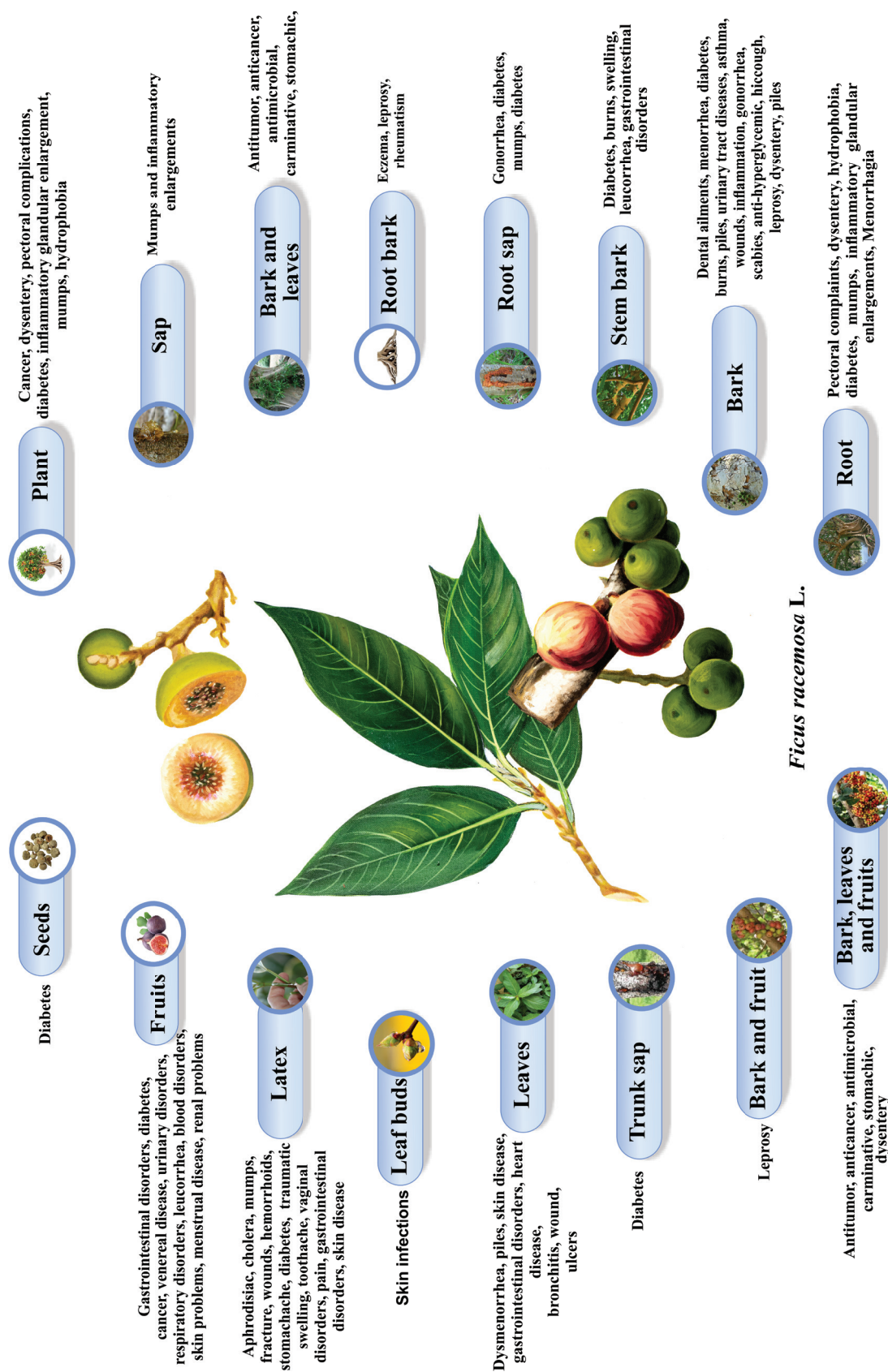


Fig. 1 Various medicinal values of *F. racemosa*

Ethnomedicinal and Folk Treatments along the Ganga Basin of India

The Ganga River, a source of life for millions of people, is referred to as the “River of India”. Of all the well-known rivers in the world, this one is the most frequently written about and revered. Although several rivers were part of the civilization in prehistoric and ancient times, Ganga is the most revered, mythological, and sacred of them. With millions of devoted followers, it symbolizes our customs and values while also nourishing the body and soul. There is a wealth of classical and traditional literature about this holy river, also called “Divine River or Devnadi” by others (Kumar, 2001). Riparian flora is the ecological term for the extremely active vegetation along rivers. A specific kind of vegetation that grows along the banks of rivers, also known as the river’s riparian zone, connects terrestrial and aquatic habitats. This habitat is influenced by waterways like rivulet banks or riverbanks (Ranjit et al., 2011). Uttarakhand and Uttar Pradesh are the two Indian states that make up the upper Ganga basin. This region has four significant towns: Rishikesh, Haridwar, Garhmukteshwar, and Narora (Kumar, 2001). Asteraceae, Euphorbiaceae, Moraceae, Malvaceae, Lamiaceae, Mimosaceae, Papilionaceae, Convolvulaceae, and Urticaceae are a few of the significant families that are said to be the dominating families in these locations (Gangwar and Gangwar, 2011). Three Indian states, namely West Bengal, Bihar, and Uttar

Pradesh, make up the middle Ganga basin. Varanasi, Buxar, Patna, Bhagalpur, and Farakka are among the five significant cities in this region (Siddiqui, 1991).

Medicinal plants were one of the main sources of crude remedies used in numerous ancient medical systems around the world (Jayaprasad et al., 2012; Thorsen et al., 2016). The therapeutic properties of plants were discovered through extensive self-experiments that took thousands of years to develop. Due to the lack of appropriate screening methods, the use of items produced by plants has reduced during the past 20 years. It is estimated that just 10% of the world’s biodiversity has had its therapeutic properties examined (Chhetri et al., 2008; Dias et al., 2012; Harvey et al., 2015;). However, using these resources and evaluating their therapeutic potential has not received top emphasis in efforts to enhance the quality of life (Dhami et al., 2008). Due to the use of innovative technological breakthroughs in biological activity screening and chemical analysis, researchers’ interest in naturally occurring compounds has increased in recent years. It is necessary to investigate several active compounds derived from both terrestrial and marine sources (Harvey et al., 2015). The careful examination of historically used plants in their natural habitats in this situation will surely be beneficial for the identification of medicinally valuable species

(Adhikari et al., 2019). Due to the presence of certain chemical components in plant tissues that have a specific physiological impact on the living biological body, thousands of plants, both known and unknown, in the plant kingdom, create medicine or pharmaceuticals. Traditional medicine utilizes hundreds of different plant species as cures for bacterial, fungal, and viral skin ailments. India is a treasure trove of healing plants. Indian culture has a very long history of using plants for ceremonial purposes as well as for illness treatment, giving the art of herbal medicine a very deep background (Kumar et al., 2022). Studies were conducted for the ethnomedicinal potential of *F. racemosa* in the Indian regions of Uttarakhand, Uttar Pradesh, Jharkhand, Bihar, and West Bengal along the Ganga Basin.

Uttarakhand: Uttarakhand is in India's northern region. The Himalayas, the Shivalik, and the terrain region are the three physiographic zones that make up the state. Mountainous topography makes up the majority of Uttarakhand. There are 13 administrative districts in the state, with one of the most significant ones, Haridwar, consisting of plain and mountainous terrain. Aquatic flora, which includes plants in ponds, marshes, reservoirs, and other waterlogged regions, is abundant across the region. Many significant aquatic medicinal plants can be found in abundance in these marshes. Different plant species are traditionally used by the locals to treat a variety of illnesses in their daily lives. Local populations have discovered the therapeutic uses of thousands of plants found in every

ecosystem, down to the coastal plains, from the north to the north-west Himalayan region (Arora, 1981). In the Indian state of Uttarakhand, one of the districts is Haridwar, originally known as Mayapuri. Haridwar offers a tapestry of Indian culture and civilization and is a paradise for nature enthusiasts as well as one of the seven holiest locations in Hinduism. The region has a huge variety of plants, and many of these are utilized as traditional medicines to cure a variety of illnesses (Kumar et al., 2022). The Tharu tribes in Udham Singh Nagar utilize the latex of the *F. racemosa* shrub to treat boils and other skin conditions. In addition, the Gujjar Community employs this plant to treat a variety of skin conditions, including leprosy, which is treated with 1-2 teaspoons of fruit decoction taken once a day for two weeks. Leaf paste is also used to treat wounds. Additionally, it functions as a tyrosinase inhibitor, antioxidant, antibacterial, and anti-inflammatory agent (Sharma et al., 2014). The plant, also known as 'gular' in the Almora district, is used to prevent conception by giving pregnant women three doses a day for 12 days of the unripe fruit juice boiled with water as well as residents of the Haridwar district utilized the bark paste of *F. racemosa* to treat eczema (Kumari et al., 2011; Kumar et al., 2022).

Uttar Pradesh: Regarding Uttar Pradesh, the state's climate supports a wide variety of medicinal plants. With three distinct seasons, winter from October to February, summer from March to mid-June, and the rainy season from June to September, and the tropical monsoon season, the average temperature in

the plains varies from 3 to 4°C in January to 43–45°C in May and June. The rainfall in the plains is heaviest in the east and decreases toward the northwest, making this land a rich zone of various medicinal plants (Mishra et al., 2012). The fruits and bark of *F. racemosa*, one of the many plant species found around Uttar Pradesh, are used to cure diabetes and dyspepsia in the Kannauj area of Uttar Pradesh (Verma et al., 2021). The roots of this plant were utilized by locals in the Sonbhadra area to treat diabetes and diarrhea. To treat dysentery, dried fruit powder mixed with latex is given three times daily for three days. Stem bark decoction is used to treat diarrhea (Kant and Pandey, 2021). In Bahraich, this plant is widely used for therapeutic purposes, including the use of fruit juice for stomachaches, bark preparation for aching joints, and fruit juice for leukorrhea (Sahani et al., 2016). Furthermore, *F. racemosa* was employed in the Moradabad region for a wide range of therapeutic uses, such as the treatment of external burning, skin irritation, diarrhea, and dysentery, as well as astringent, carminative, vermifuge, and anti-dysentery medications. The bark decoction was employed as an anti-infertility medication, and the fruit extract was used to treat diabetes, leukoderma, and skin wound irritation (Kumar et al., 2018). In the Mirzapur and Sonbhadra region of Eastern Uttar Pradesh, its leaves and roots are used as a decoction, powder, or paste to cure diarrhea, dysmenorrhea, ulcers, tonsillitis, gonorrhea, skin diseases, cough, and fatigue (Singh et al., 2023). In Mirzapur, a different region of India, the crushed fruits of this plant were also used to treat red eyes

by applying them to the forehead. Additionally, it is used to treat cancer, piles, pediatric lung disease, stomachache, urinary issues, and skin cracks on heels. Likewise, it also has febrifuge and astringent properties (Khanna et al., 1996). In Varanasi, people also utilize the fruits and juice of this plant to treat urinary issues and the leaves to treat bronchitis (Patel et al., 2020).

Jharkhand: With around 23,605 sq km of forestland, or 29% of its entire land area, Jharkhand State is incredibly rich in biological diversity and traditional wisdom (Anonymous, 2003). Due to the high percentage of tribal people and the diversity of medicinal plants in the state of Jharkhand, this knowledge of traditional medicine is abundant (Lal and Singh, 2012). About 80% of people live in rural areas, and it is also quite rich in ethnomedicine. Locally known as ‘Kavirajas’ or ‘Vaidyas’, traditional herbalists may be found in practically every community. These traditional herbalists effectively treat a variety of illnesses using local resources including animals, plants, minerals, etc. The leaders of the villages used to provide some folklore medicine in addition to practicing traditional herbal medicine. The therapeutic plants lived in their minds and spirits, and the knowledge of ethnomedicine was passed down verbally from one ethnic group to another (Jain et al., 2004). In the Latehar region of Jharkhand, the root sap is mixed with *mishri* and administered orally to treat jaundice. The unripe fruits are chewed and swallowed to treat female infertility (Marandi et al., 2014). The Santhal tribes of Sahibganj utilized the bark and

leaves of this plant as a paste or decoction to cure gonorrhea and infected wounds (Hebrom et al., 2017). In another region of Jharkhand, *F. racemosa* ripe fruits are also used to treat potency, while the roots and fruits are used to treat tuberculosis (Kumar et al., 2012).

Bihar: The tribal communities of Bihar have a very fascinating knowledge of medicinal plants. The 66,16,614 tribal people who live in Bihar make up about 10% of all the people who live in tribal areas in India. The Santhal tribe, one of the largest in India, is in the Santhal Pargana region of Bihar, which is a place where ethnobotanists find inspiration for their work. Other tribal groups are prevalent in Chotanagpur, Santhal, and Paharia. When the tribal people suffer from any kind of illness, they always utilize their ethnomedicinal plants (Kumar et al., 1998). In West Champaran, Bihar, the unripe fruit extract of *F. racemosa* is used twice or three times a day to cure diarrhea and dysentery. When they have piles, members of the Tharu tribes drink warm water and take pounded ripe fruits to reduce their discomfort (Singh et al., 2014; Singh et al., 2015). Further, in Gopalganj, the roots of

this plant are also used as a laxative, to cure diabetes and diarrhea (Prasad et al., 2014).

West Bengal: In addition to 1600 plant species of ethnobotanical importance and 850 plant species of ethnomedicinal importance to various indigenous or ethnic tribal communities of Bengal, the Indian state of West Bengal was reported to have 3580 species of angiosperm plants, 21 species of gymnosperm, 416 species of pteridophytes, 771 species of bryophytes, 873 species of algae, 539 species of fungi, and 329 species of lichens (Bandyopadhyay et al., 2021). People in distant and rural areas of India, especially in West Bengal, still rely on traditional medicines to cure a variety of illnesses (Shukla and Chakravarty, 2012). In the Alipurduar area of West Bengal, the Santhal people used latex and water to treat diarrhea (Mandal et al., 2020). As well as in the Dakshin Dinajpur region, the fruit of this plant is used as a vegetable to treat anemia and nutritional deficiencies. Additionally, a decoction produced from the root is used to heal stomach ulcers, and its leaf extract is administered topically to the skin to prevent rashes (Sarkar et al., 2023).

Conclusion and Future Perspectives

The study of herbal medicine covers the entire spectrum, including the investigation of the origin, physical and chemical characteristics, action mechanisms, absorption, distribution, biotransformation, excretion, and therapeutic applications of “drugs”. The study of herbal medicine is still in its early stages in many ways. The previous few decades have already

seen a sizable amount of research on the phytochemistry, biological functions, and therapeutic properties of various parts of *F. racemosa*. Since, very little research has been done on the biological activity and potential medical uses of this species, further study is required to fully utilize their therapeutic utility in the treatment of various illnesses. Different

parts of the *F. racemosa*, including the roots, fruits, leaves, stem, seeds, latex, and even the entire plant, have been advocated for use in traditional medicine to cure conditions like diarrhea, gastric ulcers, diabetes, high blood pressure, and wound healing. It is a well-known plant in traditional indigenous medical systems like Ayurveda, Siddha, Unani, and homeopathy. On the other hand, India has approximately 400 distinct tribal and other ethnic groups, which together make up about 7.5% of the country's total population. The natural resources nearby have helped

tribal, rural, and primitive communities find solutions for practically all their demands and concerns, including sickness treatment. Due to the numerous little-known and unknown medicinal virtues, particularly those of plant origin, that are revealed by ethnomedicinal studies, modern scientific methods such as phytochemical analysis, pharmacological screening, therapeutic aspects, and clinical trials are required for their evaluation. To explore the untapped potential of this plant, additional clinical, pharmacological, and medicinal studies must be carried out.

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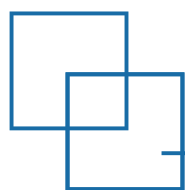
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CHAPTER
05

Phytochemical Analysis



INTRODUCTION

Ficus racemosa, commonly known as the cluster fig or ‘gular’, is a prominent tree species that holds significance in both local and global contexts. Widely distributed in tropical and subtropical regions, this versatile plant has gained attention for its diverse medicinal properties and rich phytoconstituent profile. *F. racemosa* exhibits a broad distribution, thriving in regions across Asia, particularly in India, where it is found along the Gangetic belt, the Western Ghats, and various other locations. The tree has also acclimatized to diverse environments, extending its presence to Southeast Asia, Australia, and parts of Africa. The adaptability of this species to different climates underscores its ecological resilience and contributes to its widespread occurrence (Pahari et al., 2022).

With a long history of traditional use in Ayurveda and other indigenous healing systems, *F. racemosa* is renowned for its medicinal properties. The plant has been employed in folk medicine for the treatment of various ailments, including diabetes, gastrointestinal disorders, respiratory issues, and skin conditions. Scientific investigations have supported several of these traditional uses, revealing the tree's pharmacological potential. Notably, it has demonstrated antioxidant, anti-inflammatory, antimicrobial, and anti-diabetic activities in various studies, substantiating its therapeutic value (Yadav et al., 2015; Bagyalakshmi 2019).

The medicinal efficacy of the species can be attributed to its rich phytoconstituent profile. The plant is known to contain a variety of bioactive compounds, including tannins, saponins, flavonoids, and phenolics. These phytochemicals contribute to the plant's diverse therapeutic actions, ranging from antioxidant effects linked to phenolic compounds to anti-inflammatory properties associated with flavonoids. Furthermore, specific compounds such as chlorogenic acid derivatives have been identified in *F. racemosa*, adding to the complexity of its phytochemical composition (Sumi et al., 2016; Suriyakalaa et al., 2022; Kanna et al., 2023). The phytochemical composition of this species makes it a promising candidate for various pharmacological applications.



Sampling Sites

The species was sampled from 12 different locations across five different states spread over the Gangetic course. The details of the same are presented below in Table 1.

Table 1 Sampling sites for the *Ficus racemosa* plants collected from five different states spread over the Gangetic course

S. No.	Sampling sites
1.	Narora, Uttar Pradesh
2.	Farrukhabad, Uttar Pradesh
3.	Dalmau, Uttar Pradesh
4.	Prayagraj, Uttar Pradesh
5.	Mirzapur, Uttar Pradesh
6.	Varanasi, Uttar Pradesh
7.	Ballia, Uttar Pradesh
8.	Revelganj, Bihar
9.	Farka, Bihar
10.	Sahibganj, Jharkhand
11.	Farraka, West Bengal
12.	Gomukh, Uttarakhand

Phytochemical Analysis

Phytochemical components like tannin (by titration), total saponins (by gravimetry), total polyphenols, and total flavonoids (by UV-visible spectrophotometer), were determined for their respective contents via in-house protocols using API standards and literature, developed in Chemical Science Division, Drug Discovery and Development Department, Patanjali Research Foundation, Haridwar. For the identification and quantification of secondary metabolites and active components of the samples collected, advanced methods and techniques were used. High performance

thin layer chromatography (HPTLC), was used to detect the presence of marker compounds and provide a chromatographic fingerprint of the plant sample. The hyphenated techniques have been proven as a powerful tool for the identification and structural characterization of known compounds. Hence, for further identification of compounds high-performance liquid chromatography (HPLC), and ultra performance liquid chromatography quadrupole time-of-flight mass spectrometry (UPLC/MS-QToF) were used.

Determination of Tannin Content

A representative sample weighing 1–10 g was collected and combined with 50 ml of milli-Q water. The mixture was vigorously shaken and subsequently sonicated for 30 minutes. The final volume was adjusted to 100 ml and filtered accordingly. Following this, 10 ml of the solution was withdrawn, and replaced with 750 ml of milli-Q water. Next, 25 ml of indigo sulphonic acid was thoroughly mixed with the solution. The titration process commenced with the utilization of 0.1N potassium permanganate solution, continuing until the endpoint was achieved, characterized by a distinct golden yellow hue. A blank solution with no input was also run simultaneously to serve as a control.

Determination of Saponin Content

A 5 g sample was added to a solution of 50 ml of a 1:1 methanol-water solvent. The mixture was then allowed to reflux for 1 hour before being cooled and filtered. This process was repeated three times to ensure thoroughness. The resulting filtrate was combined and concentrated. The concentrated solution was then evaporated until it became dry. Next, 25 ml of petroleum ether was introduced into the dried solution and refluxed for 10 minutes. Once cooled, the ether layer was decanted. Subsequently, 10 ml of methanol and 100 ml of acetone were added to the mixture, which was then filtered. Following this step, the filter paper containing the residue was dried at a temperature of 80°C for 1 hour. Finally, the

dried filter paper along with the residue was weighed. This meticulous procedure ensures accurate and reliable results.

Determination of Total Polyphenol Content

A 1 ml of sample was collected, which subsequently was transferred into a test tube. Following this, a 1 ml portion of the Folin–Ciocâlteu reagent was introduced to the sample, allowing it to incubate undisturbed for 5 minutes. Subsequently, 1 ml of a 10% sodium carbonate solution was carefully added to the mixture. The test tube must be kept shielded from light for 1 hour to secure accurate results. Upon the culmination of the incubation period, the absorbance at a wavelength of 760 nm was measured using a UV-visible spectrophotometer. To ensure precision, it is advisable to repeat the entire procedure using gallic acid as a standard reference. This would permit the generation of a linear plot, which will greatly assist in the careful interpretation of the obtained outcomes.

Determination of Total Flavonoid Content

1 ml of sample was obtained and transferred into a test tube. Then, 0.4 ml of 10% aluminum chloride, 0.4 ml of sodium acetate, and 3 ml of ethanol were added to the test tube. The mixture was kept at room temperature for 30 minutes. Subsequently, absorbance was measured at 450 nm using a UV-visible spectrophotometer. To establish linearity, the same procedure was repeated using quercetin dihydrate as a reference standard.

HPTLC Fingerprinting

The application of High performance thin-layer chromatography (HPTLC) in the study mirrors a prevalent methodology documented in the literature for profiling secondary metabolites. The use of HPTLC not only enables the rapid separation of compounds but also aligns with the commonly reported diverse chemical fingerprints found in *Ficus* species. This technique has been recognized for its effectiveness in exploring the qualitative aspects of secondary metabolites in various plant species.

Sample Preparation

Approximately 1 gm of powdered leaf sample from each batch was individually dissolved in 10 ml of methanol. The samples were vigorously shaken and sonicated for 20

minutes. Subsequently, the solution was centrifuged for 5 minutes at 5000 rpm. The resulting clear solution was then utilized for analysis. The samples were carefully spotted according to the corresponding serial numbers specified in Table 1.

Methodology and Analytical Conditions

Analysis was performed on CAMAG HPTLC (Muttens, Switzerland), equipped with an Automatic TLC Sampler (ATS 4), TLC scanner 4 and TLC visualize. Data processing acquisition and visualization were achieved using win-CATS software (version 1.4.10). The chromatographic conditions for the HPTLC analysis were as follows:

Stationary phase	TLC Silica gel 60 F254 aluminium sheet (1.0554.0007)
Mobile phase	Ethyl acetate: Formic acid: Acetic acid: Water (10: 1.1: 1.1: 2.3)
Saturation time	10 minutes
Migration distance	70 mm
Band length	8 mm
Injection volume	25 µl
Visualization	254 nm and 366 nm before derivatization

High-Performance Liquid Chromatography (HPLC)

Sample and Standard Preparation

Sample: About 1.5 gm of the sample was dissolved in 25 ml of water: methanol (50:50), sonicated for 2 hours at 60°C and filtered through 41 number Whatman filter paper. The extraction was repeated one more time before all the extracts were pooled together and made the volume up to 50 ml. Lastly, it was filtered through a 0.45 µm filter paper before using it for the analysis.

Standard: Prepared mix standard of neochlorogenic acid, chlorogenic acid and cryptochlorogenic acid of 50 ppm from 1000 ppm stock solutions.

Analytical and Instrumentation Condition

Analysis was performed on Prominence-i HPLC system (Shimadzu, Japan). Separation was achieved using a Shodex C18-4E (5 µm, 4.6 × 250 mm) column subjected to binary gradient elution. The two solvents used for the analysis were water containing 0.1% acetic acid in water (solvent A) and acetonitrile (solvent B). Column temperature was kept 35°C and flow was set 1.0 ml/min during the analysis. Ten microliters of standard and test solution were injected. Wavelength set at 325 nm (for neochlorogenic acid, chlorogenic acid and cryptochlorogenic acid).

Gradient program used

Time (Min)	A%	B%
0.01	100	0
5	95	5
10	92	8
15	88	12
20	80	20
30	65	35
40	45	55
50	5	95
55	95	5
60	95	5

Identification of compounds by Ultra Performance Liquid Chromatography Quadrupole Time-of-Flight Mass Spectrometry (UPLC/MS-QToF)

Test sample: *Ficus racemosa* (PRF/CHI/1023/1004): Narora, Uttar Pradesh

Sample Preparation

A 250 mg sample was dissolved in 5 ml methanol-water (50:50) solution and sonicated for 30 min. The solution was centrifuged at 10000 rpm for 5 minutes and filtered through a 0.22 µm nylon filter before analyzing under UPLC.

Analytical and Instrumentation Conditions

Analysis was performed on a Xevo G2-XS QToF (Waters Corporation, USA) with Acquity UPLC-I Class and Unifi software. Separation was

carried out using ChromCore 120 C18 (100 x 2.1 mm, 1.8 µm) column with a flow rate of 0.3 ml/min using gradient elution of 0.1 % formic acid in water (mobile phase A) and 0.1 % formic acid in acetonitrile (mobile phase B). The column was maintained at 30°C throughout the analysis and sample temperature was kept at 20°C. Detection was carried out by Xevo G2-XS QToF. Two microlitres of test solution was injected in UPLC/MS-QToF and chromatograms were recorded in positive and negative ionization mode. The following gradient program was used for the run.

Gradient program used

Time (min)	Flow rate (ml/min)	Mobile phase A%	Mobile phase B%
0	0.3	98	2
2	0.3	98	2
10	0.3	95	5
25	0.3	85	15
50	0.3	50	50
60	0.3	30	70
61	0.3	98	2
65	0.3	98	2

Xevo G2-XS QToF Parameters:

Parameter	Polarity (+ve)	Polarity (-ve)
Ionisation type	ESI	ESI
Mode	MS ^E	MS ^E
Mass range (m/z)	50-1200 m/z	50-1200 m/z
Scan time	0.5 s	0.5 s
Cone Voltage	40 V	40 V
Capillary	1.0 kV	2.0 kV
Low CE	6.0 eV	6.0 eV
High CE	15-60 eV(ramp)	15-60 eV(ramp)
Source temperature	120°C	120°C
Desolvation Temperature	500°C	500°C
Cone gas flow	50 L/h	50 L/h
Desolvation gas flow	900 L/h	900 L/h
Lock Spray (Leucine Enkaphalin)	556.2766 m/z	554.2620 m/z
Lock mass scan time	0.5 s	0.5 s
Lock mass interval	30 s	30 s

Results and Discussion

Phytochemical Analysis

The quantitative phytochemical analysis of *F. racemosa* revealed the presence of tannins, saponins, total phenolics, and total flavonoids in varying concentrations across different geographical locations (Table 2). The presence and concentration of these compounds are crucial for understanding the medicinal potential of the plant. The following insights can be drawn from the results:

- ◆ **Tannins:** The tannin content ranged from 0.019% to 0.179%. The highest concentration was found in samples from Farraka, West Bengal (0.179%), which could be attributed to the unique environmental conditions of the region.

Tannins are known for their astringent properties and potential health benefits, including antioxidant and anti-inflammatory effects.

- ◆ **Saponins:** Saponin content varied significantly, with the highest concentration found in Gaumukh, Uttarakhand (9.43%). Saponins are known for their antimicrobial and anti-inflammatory properties, making these samples potentially valuable for medicinal use.
- ◆ **Total Polyphenols:** The polyphenol content ranged from 0.067% to 1.446%, with the highest value observed in Farraka, West Bengal. Polyphenols are important for their antioxidant activity, which contributes to the plant's therapeutic potential.

- ◆ **Total Flavonoids:** The flavonoid content was relatively low across all samples, with the highest being 0.058% in Narora and Farrukhabad, Uttar Pradesh. Flavonoids are known for their antioxidant, anti-inflammatory, and cardioprotective properties.
- ◆ These variations in phytochemical content highlight the influence of geographical and environmental factors on the phytochemical profile of *F. racemosa*.

Table 2 Phytochemical analysis of *Ficus racemosa* collected from different locations in five different states

S. No.	Samples	Tannin (%w/w)	Saponin (%w/w)	Total polyphenol(%w/w)	Total flavonoid (%w/w)
1.	Narora, Uttar Pradesh	0.020	8.32	0.180	0.058
2.	Farrukhabad, Uttar Pradesh	0.019	6.60	0.181	0.058
3.	Dalmau, Uttar Pradesh	0.019	4.98	0.120	0.039
4.	Prayagraj, Uttar Pradesh	0.020	3.78	0.118	0.033
5.	Mirzapur, Uttar Pradesh	0.020	8.57	0.178	0.026
6.	Varanasi, Uttar Pradesh	0.020	8.90	0.114	0.014
7.	Ballia, Uttar Pradesh	0.040	7.69	0.146	0.033
8.	Revelganj, Bihar	0.040	4.66	0.096	0.005
9.	Farka, Bihar	0.040	2.33	0.067	0.031
10.	Sahibganj, Jharkhand	0.040	3.70	0.138	0.024
11.	Farraka, West Bengal	0.179	4.49	1.446	0.045
12.	Gaumukh, Uttarakhand	0.020	9.43	0.210	0.021

HPTLC Fingerprint Analysis

The HPTLC fingerprint analysis provided a detailed chemical profile of *F. racemosa* samples from different locations. The chromatograms obtained under multi-wavelength detection (254 nm and 366 nm) showed distinct patterns, indicating the presence of various compounds:

- ◆ 254 nm (short wave UV): High-intensity bands were observed in samples from Narora, Farrukhabad, Dalmau, Prayagraj, Mirzapur, Varanasi, Ballia, and Gaumukh.
- ◆ 366 nm (long wave UV): Similar to the 254 nm detection, the 366 nm detection revealed high-intensity bands in the same samples, confirming the presence of compounds that exhibit fluorescence under UV light, likely flavonoids and other phenolics.

The HPTLC profiles corroborate the quantitative phytochemical analysis, demonstrating the rich diversity of bioactive compounds in *F. racemosa*. The differences in band intensity

and pattern further underscore the impact of geographical factors on the phytochemical composition of the plant (Fig 1).

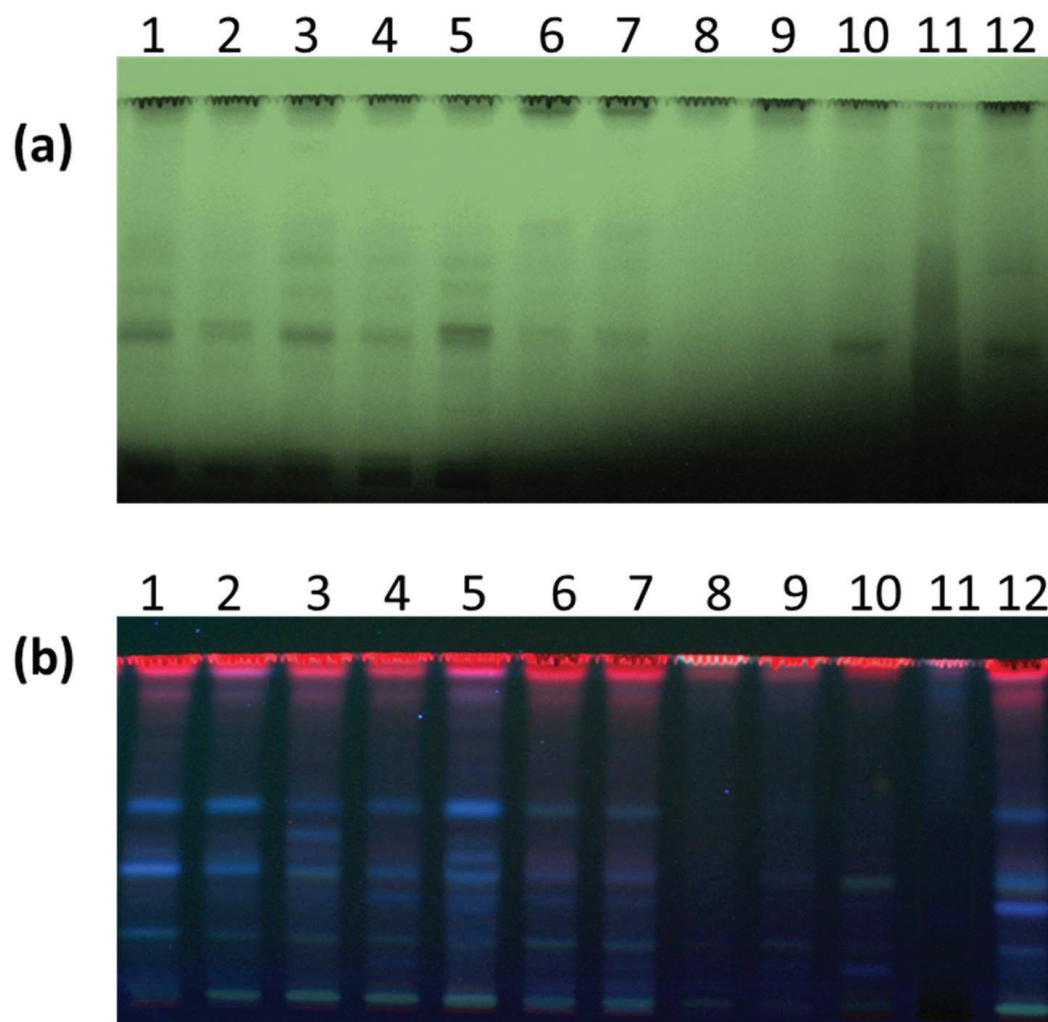


Fig. 1 HPTLC fingerprinting of *Ficus racemosa* at (a) 254 nm and (b) 366 nm (after derivatization)

HPLC Analysis

The HPLC analysis focused on identifying and quantifying specific phenolic acids (neochlorogenic acid, chlorogenic acid, and cryptochlorogenic acid) in the samples. The following observations were made:

- ◆ **Neochlorogenic Acid:** Detected in varying concentrations, with the highest levels observed in samples from Mirzapur, Uttar Pradesh. This phenolic acid is known for its antioxidant properties, contributing to the medicinal value of the plant.
- ◆ **Chlorogenic Acid:** Widely distributed across all samples, with significant

concentrations noted in Mirzapur, Uttar Pradesh. Chlorogenic acid is renowned for its antimicrobial and anti-inflammatory effects.

- ◆ **Cryptochlorogenic Acid:** Present in lower concentrations compared to the other phenolic acids but still significant in samples from Farrukhabad, Uttar

Pradesh. This compound also exhibits antioxidant activity.

The gradient elution program used in HPLC allowed for efficient separation and detection of these phenolic acids, providing a clear phytochemical profile that supports the plant's traditional medicinal uses.

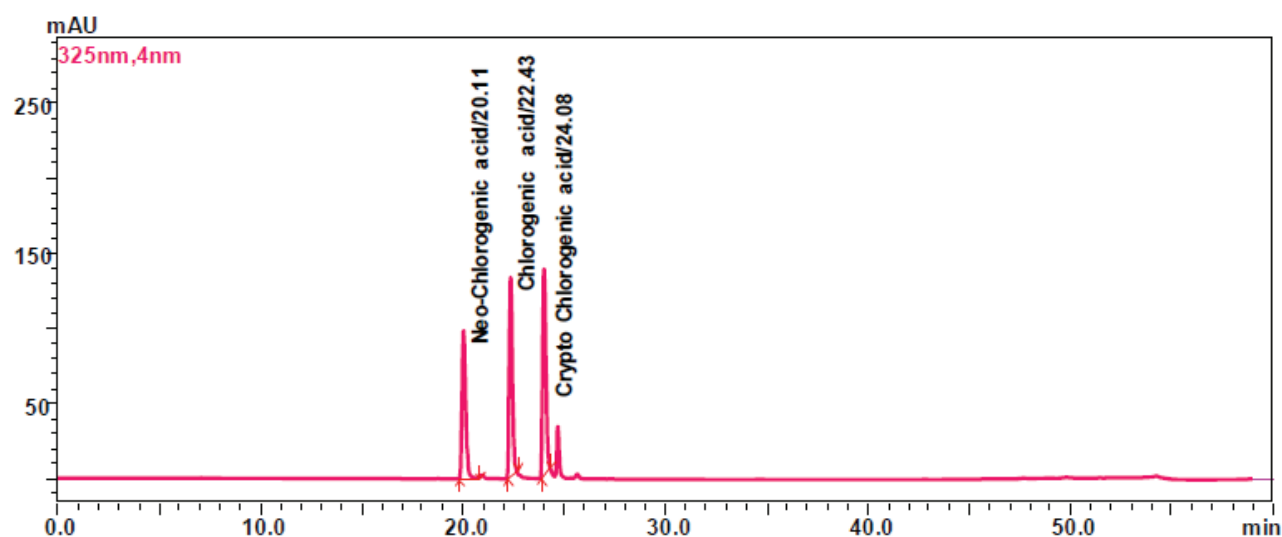


Fig. 2 HPLC profile of mix reference standard

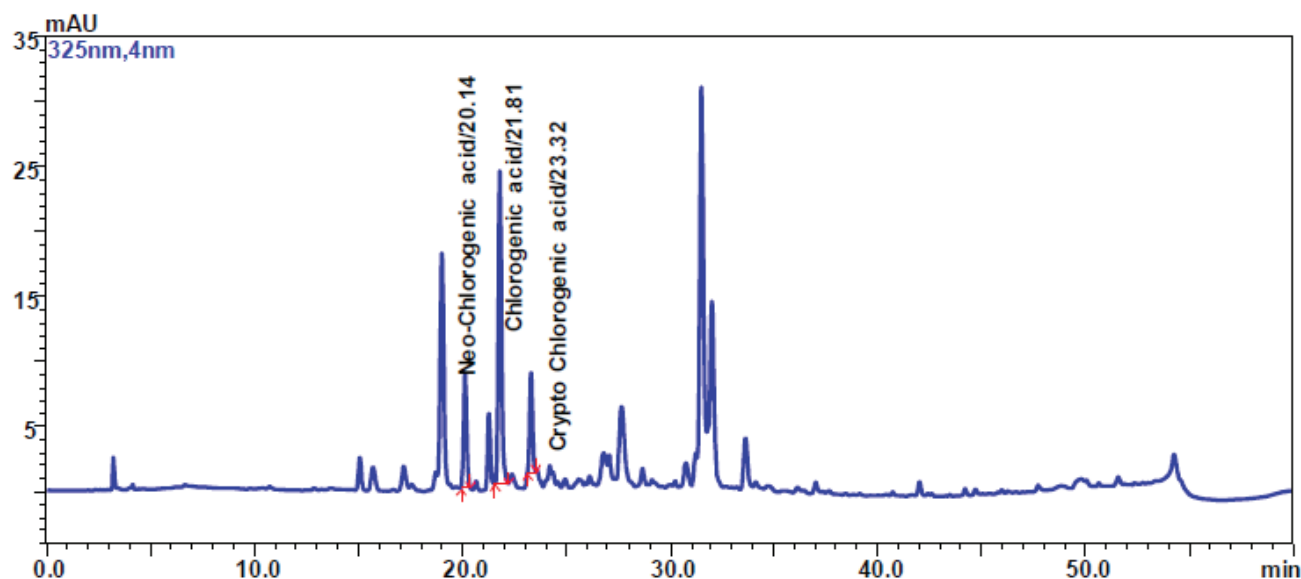


Fig. 3 Representative HPLC profile of *Ficus racemosa* raw material

Table 3 Phytochemical content present in *Ficus racemosa* collected from different locations

S. No.	External code	Neochlorogenic acid (%w/w)	Chlorogenic acid (%w/w)	Cryptochlorogenic acid (%w/w)
1	Narora, Uttar Pradesh	0.011	0.028	0.007
2	Farrukhabad, Uttar Pradesh	0.048	0.035	0.025
3	Dalmau, Uttar Pradesh	0.011	0.026	0.009
4	Prayagraj, Uttar Pradesh	0.004	0.013	0.003
5	Mirzapur, Uttar Pradesh	0.028	0.077	0.021
6	Varanasi, Uttar Pradesh	0.009	0.011	0.009
7	Ballia, Uttar Pradesh	0.024	0.025	0.020
8	Revelganj, Bihar	0.010	0.001	ND
9	Farka, Bihar	0.008	0.002	ND
10	Sahibganj, Jharkhand	ND	0.005	0.002
11	Farraka, West Bengal	ND	ND	ND
12	Gaumukh, Uttarakhand	0.021	0.062	0.018

ND: Not Detected, detection level Neochlorogenic acid 2 ppm, Chlorogenic acid 1.5 ppm and Cryptochlorogenic acid 1.5 ppm

UPLC/MS-QToF Analysis

The analysis resulted in a fast, high-resolution separation with high sensitivity. The qualitative (identification of compounds), and relative quantification (response curve) were obtained

for a variety of substances within the complex mixture. The TIC chromatogram as well as the list of identified compounds and their associated parameters in both positive and negative modes have been presented below. A total of 26 compounds were consequently identified.

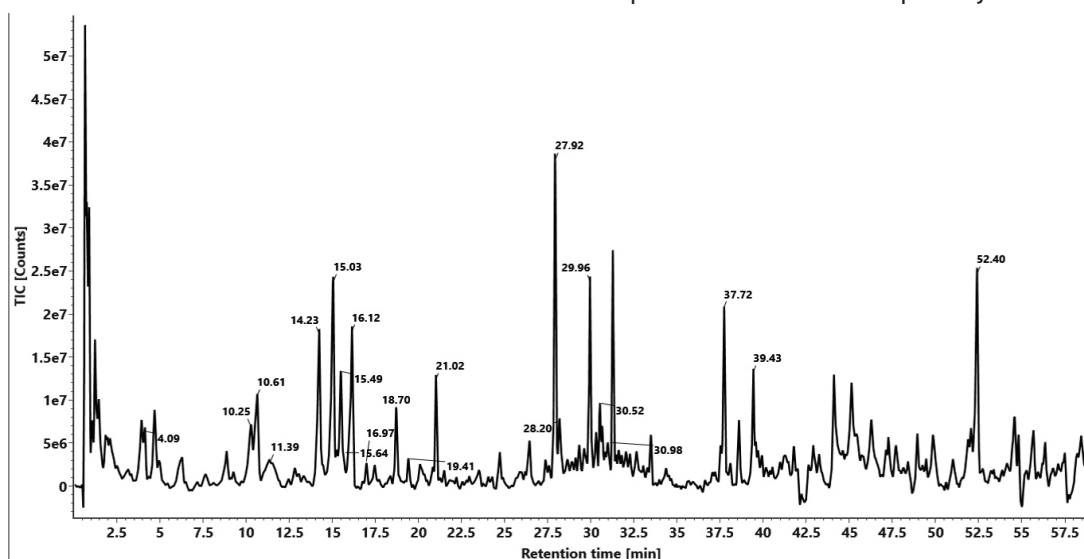


Fig. 4 TIC chromatogram of *Ficus racemosa* (PRF/CHI/1023/1004) in positive ionization mode

Table 4 Compound-dependent parameters of analytes/identified compounds in *Ficus racemosa* (PRF/CHI/1023/1004) in positive ionization mode

S. No.	Component Name	Formula	Neutral mass(Da)	Observed m/z	Mass error (mDa)	RT (min)	Response	Adducts
1	Methyl 3-O-β-glucopyranosyl-gallate	C ₁₄ H ₁₈ O ₁₀	346.0900	369.0784	-0.8	4.09	11191	+Na
2	Neochlorogenic acid	C ₁₆ H ₁₈ O ₉	354.0951	355.1016	-0.8	10.25	83984	+H
3	Racemosic acid	C ₂₂ H ₂₈ O ₁₄	516.1479	517.1550	-0.2	10.61	1619034	+H
4	Dihydroferulic acid 4-O- glucuronide	C ₁₆ H ₂₀ O ₁₀	372.1057	373.1123	-0.6	11.39	877060	+H
5	5-O-(3'-O-Glucosylcaffeoyl) quinic acid	C ₂₂ H ₂₈ O ₁₄	516.1479	517.1556	0.4	12.79	194268	+H
6	Bergenin	C ₁₄ H ₁₆ O ₉	328.0794	329.0861	-0.6	14.23	686783	+H
7	Unknown compound 1	NA	NA	355.1016	NA	15.03	2788815	NA
8	Chlorogenic acid	C ₁₆ H ₁₈ O ₉	354.0951	355.1013	-1.1	15.49	383830	+H
9	6-O-(2,4-Dihydroxy-6-methylbenzoyl)-α-D-glucopyranosyl α-D-glucopyranoside	C ₂₀ H ₂₈ O ₁₄	492.1479	493.1545	-0.7	15.64	139372	+H
10	Unknown compound 2	NA	NA	355.1018	NA	16.12	1829011	NA
11	Cryptochlorogenic acid	C ₁₆ H ₁₈ O ₉	354.0951	355.1013	-1.1	16.97	49166	+H
12	Quercetin 3,7-diglucuronide	C ₂₇ H ₂₆ O ₁₉	654.1068	655.1141	0.0	18.70	546494	+H
13	Quercetin 3-glucoside-7-glucuronide	C ₂₇ H ₂₈ O ₁₈	640.1276	641.1352	0.4	19.41	192018	+H

S. No.	Component Name	Formula	Neutral mass(Da)	Observed m/z	Mass error (mDa)	RT (min)	Response	Adducts
14	Luteolin 7-O-diglucuronide	C ₂₇ H ₂₆ O ₁₈	638.1119	639.1193	0.1	21.02	1007826	+H
15	Quercetin-3-Glucuronide	C ₂₁ H ₁₈ O ₁₃	478.0747	479.0815	-0.5	27.92	1797493	+H
16	Kaempferol-3-Glucuronide	C ₂₁ H ₁₈ O ₁₂	462.0798	463.0865	-0.6	28.20	469110	+H
17	Isochlorogenic acid A	C ₂₅ H ₂₄ O ₁₂	516.1268	517.1339	-0.2	29.30	40341	+H
18	Isochlorogenic acid B	C ₂₅ H ₂₄ O ₁₂	516.1268	517.1337	-0.3	29.61	181922	+H
19	Kaempferol-3-o-glucuronide	C ₂₁ H ₁₈ O ₁₂	462.0798	463.0867	-0.4	29.96	1345817	+H
20	Apigenin 7-glucuronide	C ₂₁ H ₁₈ O ₁₁	446.0849	447.0917	-0.5	30.52	614642	+H
21	Isochlorogenic acid C	C ₂₅ H ₂₄ O ₁₂	516.1268	517.1338	-0.2	30.98	27913	+H
22	2,3,4-Trihydroxy-2,4-octadecadienoic acid	C ₁₈ H ₃₂ O ₅	328.2250	351.2134	-0.8	37.72	124630	+Na
23	7,10,12-trihydroxy-8-octadecenoic acid	C ₁₈ H ₃₄ O ₅	330.2406	353.2292	-0.7	39.43	119483	+Na
24	17-Hydroxylinolenic acid	C ₁₈ H ₃₀ O ₃	294.2195	317.2072	-1.5	52.40	21328	+Na

NA: Not applicable

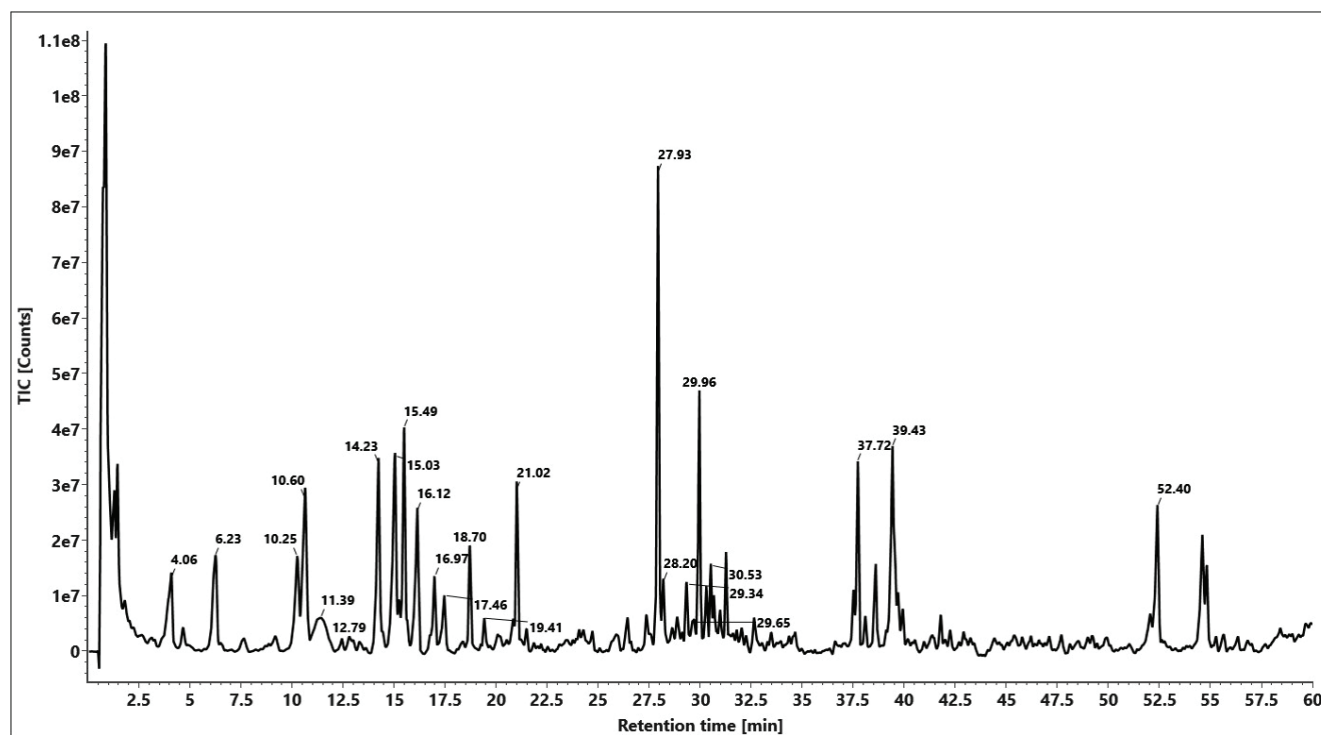


Fig. 5 TIC chromatogram of *Ficus racemosa* (PRF/CHI/1023/1004) in negative ionization mode

Table 5 Compound-dependent parameters of analytes/identified compounds in *Ficus racemosa* (PRF/CHI/1023/1004) in negative ionization mode

S. No.	Component Name	Formula	Neutral mass(Da)	Observedm/z	Mass error (mDa)	RT (min)	Response	Adducts
1	Methyl 3-O-β-glucopyranosyl-gallate	C ₁₄ H ₁₈ O ₁₀	346.0900	345.0831	0.3	4.06	2281577	-H
2	Protocatechuic acid-3- glucoside	C ₁₃ H ₁₆ O ₉	316.0794	315.0725	0.4	6.23	2255996	-H
3	Neochlorogenic acid	C ₁₆ H ₁₈ O ₉	354.0951	353.0881	0.3	10.25	2115000	-H
4	Racemosic acid	C ₂₂ H ₂₈ O ₁₄	516.1479	515.1407	0.1	10.60	3429231	-H
5	Dihydroferulic acid 4-O- glucuronide	C ₁₆ H ₂₀ O ₁₀	372.1057	371.0988	0.5	11.39	3542210	-H
6	5-O-(3'-O-Glucosylcaffeoyl) quinic acid	C ₂₂ H ₂₈ O ₁₄	516.1479	561.1472	1.1	12.79	262917	+HCOO

S. No.	Component Name	Formula	Neutral mass(Da)	Observedm/z	Mass error (mDa)	RT (min)	Response	Adducts
7	Bergenin	C ₁₄ H ₁₆ O ₉	328.0794	327.0721	-0.1	14.23	3275098	-H
8	Unknown compound 1	NA	NA	353.0883	NA	15.03	4716506	NA
9	Chlorogenic acid	C ₁₆ H ₁₈ O ₉	354.0951	353.0883	0.5	15.49	2141972	-H
10	6-O-(2,4-Di-hydroxy-6-methylbenzoyl)-α-D-glucopyranosyl α-D-glucopyranoside	C ₂₀ H ₂₈ O ₁₄	492.1479	491.1411	0.5	15.64	575274	-H
11	Unknown compound 2	NA	NA	353.0883	NA	16.12	3685996	NA
12	Cryptochlorogenic acid	C ₁₆ H ₁₈ O ₉	354.0951	353.0879	0.0	16.97	1214955	-H
13	2-(2-Hydroxyphenyl) succinic acid	C ₁₀ H ₁₀ O ₅	210.0528	209.0453	-0.2	17.46	1048329	-H
14	Quercetin 3,7-diglucuronide	C ₂₇ H ₂₆ O ₁₉	654.1068	653.0980	-1.6	18.70	1485231	-H
15	Quercetin 3-glucoside-7-glucuronide	C ₂₇ H ₂₈ O ₁₈	640.1276	639.1200	-0.3	19.41	556959	-H
16	Luteolin 7-O-diglucuronide	C ₂₇ H ₂₆ O ₁₈	638.1119	637.1039	-0.7	21.02	1688272	-H
17	Quercetin-3-Glucuronide	C ₂₁ H ₁₈ O ₁₃	478.0747	477.0679	0.5	27.93	3746648	-H
18	Kaempferol 5-O-glucuronide	C ₂₁ H ₁₈ O ₁₂	462.0798	461.0728	0.2	28.20	772222	-H
19	Isochlorogenic acid A	C ₂₅ H ₂₄ O ₁₂	516.1268	515.1199	0.4	29.34	621032	-H

S. No.	Component Name	Formula	Neutral mass(Da)	Observedm/z	Mass error (mDa)	RT (min)	Response	Adducts
20	Isochlorogenic acid B	C ₂₅ H ₂₄ O ₁₂	516.1268	515.1199	0.4	29.65	549976	-H
21	Kaempferol-3-o-glucuronide	C ₂₁ H ₁₈ O ₁₂	462.0798	461.0729	0.3	29.96	3010750	-H
22	Apigenin 7-glucuronide	C ₂₁ H ₁₈ O ₁₁	446.0849	445.0779	0.2	30.53	683563	-H
23	Isochlorogenic acid C	C ₂₅ H ₂₄ O ₁₂	516.1268	515.1199	0.4	30.98	437626	-H
24	2,3,4-Trihydroxy-2,4- octadecadienoic acid	C ₁₈ H ₃₂ O ₅	328.2250	327.2180	0.3	37.72	2958885	-H
25	7,10,12-Trihydroxy-8- octadecenoic acid	C ₁₈ H ₃₄ O ₅	330.2406	329.2336	0.3	39.43	4847991	-H
26	17-Hydroxylinolenic acid	C ₁₈ H ₃₀ O ₃	294.2195	293.2118	-0.4	52.40	3539299	-H

NA: Not applicable

UPLC/MS-QToF provided a comprehensive analysis of the bioactive compounds in *F. racemosa*. The results revealed a complex mixture of secondary metabolites, including phenolics, flavonoids, and saponins:

- ◆ **Phenolic Compounds:** Detected in both positive and negative ionization modes, confirming the presence of multiple phenolic acids that contribute to the plant's antioxidant properties.
- ◆ **Flavonoids:** Identified through characteristic mass spectra, these

compounds are known for their anti-inflammatory and cardioprotective effects.

- ◆ **Saponins:** The analysis highlighted the presence of various saponins, which are significant for their antimicrobial and anti-inflammatory activities.

The UPLC/MS-QToF analysis provided a detailed chemical profile, corroborating the findings from HPTLC and HPLC analyses and enhancing our understanding of the bioactive compounds present in *Ficus racemosa*.

Conclusion

In the current study, a comprehensive analysis was conducted on leaves obtained from 12 distinct *Ficus racemosa* samples, sourced from various locations along the Gangetic belt. This research aimed to delve into the phytochemical composition of *F. racemosa*, shedding light on its diverse secondary metabolites. In alignment with established literature on *F. racemosa*, our analysis revealed significant variations in the phytochemical composition viz. tannins, saponins, phenolics, and flavonoids that have been consistently recognized as pivotal constituents in *F. racemosa*, contributing to its medicinal properties. Studies have often highlighted the antioxidant, anti-inflammatory, and antimicrobial potential associated with these compounds, showcasing the plant's therapeutic relevance.

Subsequently, HPTLC was employed to fingerprint the samples, enabling the identification of major compounds or secondary metabolites. The results of this technique provided a visual representation of the chemical diversity within the samples, enhancing our understanding of the plant's chemical profile.

To delve deeper into the composition, HPLC was employed to analyze the specific quantities (% w/w) of neochlorogenic acid, chlorogenic acid, and cryptochlorogenic

acid compounds in each sample. This step allowed for a more targeted examination of key bioactive compounds, shedding light on their abundance in different samples along the Gangetic belt. The utilization of HPLC to quantify these specific compounds aligns with established literature. Previous research has emphasized the importance of these compounds due to their potential health benefits, including antioxidant and anti-inflammatory properties.

Finally, the cutting-edge hyphenated technique of UPLC/MS-QToF was employed leading to the identification and quantification of 26 compounds. This advanced methodology allowed for a highly detailed and accurate characterization of the chemical constituents present in the species, further enhancing our understanding of its phytochemical complexity.

By adopting a multi-faceted approach that encompassed various analytical techniques, this study not only contributes valuable data on the phytochemical composition of the species along the Gangetic belt but also establishes a robust framework for future research endeavors in the field. The integration of traditional methods with state-of-the-art technologies ensures a comprehensive exploration of the intricate chemical landscape of this medicinal plant.

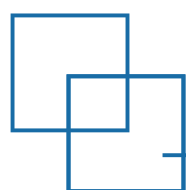
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CHAPTER

06

Insilico Analysis Against Parkinson's Disease



INTRODUCTION

Over the past few decades, numerous studies have demonstrated that Parkinson's disease (PD) is the most prevalent neurodegenerative disorder after Alzheimer's disease. It is estimated that the number of people affected by PD worldwide will increase to 14 million by 2040 (Wei et al., 2024), with older individuals exhibiting higher susceptibility compared to younger ones. The gradual deterioration of neurons within the brain, leading to their eventual demise and the disruption of dopamine neuronal functions (Krishnamurthy et al., 2022). The disease prominently exhibits two neuropathological phenomena including the demise of nigrostriatal dopamine neurons and the anomalous aggregation of α -synuclein, resulting in the development of Lewy bodies (Choong and Mochizuki, 2022). The disease classified through two key categories of symptoms, i.e., motor symptoms characterized by dyskinesia, tremor, rigidity, and postural instability, and non-motor symptoms encompassing depression, anxiety, sensory disturbances, sleep disorders, gastrointestinal dysfunction, amnesia, olfactory impairment, and dementia. Previous research has demonstrated that non-motor symptoms typically appear before motor symptoms, and a proportion of PD patients have reported gastrointestinal disorders occurring prior to the onset of motor symptoms. Monoamine oxidase (MAO), a pivotal enzyme in neurotransmitter metabolism which exists in different forms MAO-A and MAO-B with distinct substrate affinities and tissue distributions, with MAO-B playing a key role in PD by degrading dopamine (Riederer and Müller, 2018; Tsuboi et al., 2022). Current medical interventions have not fully addressed Parkinson's disease, emphasizing the crucial need for pharmaceutical advancements (Gao et al., 2024; Wei et al., 2024). This is crucial given PD's complex pathogenesis involving α -synuclein aggregation, inflammation, oxidative stress, and apoptosis, prompting exploration into medicinal plants with diverse bioactive compounds.

In the quest for effective neuroprotection against Parkinson's disease (PD), the development of novel pharmaceuticals increasingly demands the concurrent targeting of multiple pathways. Alongside this pursuit, plants have garnered significant attention in the fields of medicine and pharmacology, heralded for their promising chemotherapeutic



properties. The genus *Ficus* includes a vast collection of tropical plants, having more than 700 species. These plants grow well in the warm regions of Asia, Africa, America, and Australia (Ben et al., 2023). *Ficus racemosa* L., a species within the Moraceae family, is widely distributed throughout Southeast Asia (Pahari et al., 2022). *F. racemosa* is well-known for its medicinal properties, with various parts, including the fruit, leaves, and bark, extensively studied for their pharmacological properties. These include antidiarrheal, anti-inflammatory, antipyretic, antifungal, antibacterial, hypolipidemic, antiparasitic, and hepatoprotective (Chaware et al., 2020; Pahari et al., 2022). The fruit of this plant have been utilized in traditional medicine to treat a variety of disease, including leprosy, menorrhagia, leukorrhoea, and various blood disorders. Additionally, they have been employed in the treatment of burns, intestinal worms, dry cough, and urinary tract infections. The leaves of *F. racemosa* are particularly rich in reducing sugars, flavonoids, and minerals, making them a potent nutritional resource. The fruit is used for its easily absorbed carbohydrates, high-calorie content, and phytotherapeutic components, make it a valuable food source (Kannan et al., 2024). A diverse array of chemical compounds, including polyphenols, friedelane-type triterpenes, norfriedelane-type triterpenes, eudesmane-type sesquiterpenes, and various glycosides, have been isolated from this plant (Keshari et al., 2016).

Etiology of Disease

The etiology of Parkinson's disease (PD) is multifactorial and remains unclear, involving a complex interplay of genetic, environmental, and neurobiological factors (Lill, 2016). Genetically, mutations in specific genes such as SNCA, LRRK2, and PARK2 have been linked to familial forms of the disease, suggesting a hereditary component (Nuytemans et al., 2010). Moreover, environmentally, exposure to certain pesticides and heavy metals, along with a history of head trauma, has been associated with an increased risk of

developing PD (Ullah et al., 2021). Additionally, neurobiologically, this disease is characterized by the degeneration of dopaminergic neurons in the substantia nigra, a brain region crucial for movement control (Meder et al., 2019). The accumulation of abnormal protein aggregates called Lewy bodies, primarily composed of alpha-synuclein, is a mark of the disease and is believed to contribute to neuronal death (Lee et al., 2014). Inflammation and oxidative stress are also thought to play roles in the neurodegenerative processes underlying PD.

Reported Therapeutic Uses

Ficus racemosa, commonly known as 'cluster fig', is renowned in traditional medicine for its extensive therapeutic uses (Ahmed and Urooj, 2010). The leaf and plant exudate are utilized for treating conditions such as abdominal pain, blistering, constipation, dermatitis, hoarseness, and smallpox. The bark of this plant serves diverse purposes, acting as abortifacient agents, combating *acne vulgaris*, providing analgesic effects, and even functioning as angiotensin-converting enzyme inhibitors. It is also valued for its anthelmintic, anti-bacterial, anti-inflammatory, and anti-protozoal properties (Chaware et al., 2020). Moreover, the bark treats various disease such as hemorrhoids, hypertension, and diabetes mellitus, etc. The fruit of this plant acts as an anti-arrhythmic agent, antiemetic, and diuretic, while also help to treat various

diseases such as fatigue, cysts, and delirium (Sasidharan et al., 2023). The flowers of this plant possess antifungal properties and help in gastrointestinal diseases. Its seeds are used in treating chickenpox and as cholinesterase inhibitors. The root combat diseases like cholestasis, diabetes mellitus, eczema, fever, and mental disorders. The stem of this plant is used in treating helminthiasis, dysentery, lung diseases, and wounds. Additionally, the whole plant exhibits broad therapeutic potential, ranging from anti-neoplastic and lactation-promoting effects to treating tuberculosis and wounds (Mohiuddin and Lia, 2020). *F. racemosa* thus stands as a comprehensive botanical resource, treating a huge number of health concerns through its varied medicinal applications (Table 1).

Table 1 List of previously reported therapeutic uses of *F. racemosa*

Plant part	Therapeutic use	Therapeutic use identifiers	References
Leaves, plant exudate	Abdominal pain	MESH:D015746, UMLS:C0000737, SYMP:0000457, ICD-11:MD81.4	ISBN:9770972795006, Standardization of Single Drugs of Unani Medicine Part - IV
Bark	Abortifacient agents	MESH:D000019, UMLS:C0000782, ICD-11:JA00.1	ISBN:81-204-0828-4, ISBN:9788173717048
Plant exudate	Abscess	MESH:D000038, UMLS:C0000833, SYMP:0000672, ICD-11:1B75.3	Glimpses Of Medico-Botany of Bastar District (M.P.)
Bark	Acne vulgaris	MESH:D000152, UMLS:C0702166, D01D:6543, ICD-11:ED80.Z	ISBN:9770972795006
Leaves	Allelopathy	MESH:D064089, UMLS:C3658358	ISBN:9788172362300

Plant part	Therapeutic use	Therapeutic use identifiers	References
Bark, Leaves	Analgesics	MESH:D000700, UM-LS:C0002771, ICD-11:XM49F7	ISBN:9770972795006
Bark	Angiotensin-converting enzyme inhibitors	MESH:D000806, UMLS:C4541021	ISBN:9770972795006
Bark, fruit, Leaves, root, stem	Anthelmintics	MESH:D000871, UM-LS:C0003158, ICD-11:XM4EC0	ISBN:9770972795006, Standardization of Single Drugs of Unani Medicine Part - IV
Fruit, Leaves	Anti-arrhythmic agents	MESH:D000889, UM-LS:C0003195, ICD-11:BC9Z	ISBN:9770972795006, ISBN:9788172360481
Bark, fruit, Leaves, seed	Anti-bacterial agents	MESH:D000900, UM-LS:C0279516, ICD-11:XM8XH0	ISBN:9770972795006
Fruit	Antiemetics	MESH:D000932, UM-LS:C0003297, ICD-11:XM4VY6	ISBN:9780387706375
Bark, flower, Leaves, plant exudate, root	Antifungal agents	MESH:D000935, UM-LS:C0003308, ICD-11:XM83G4	ISBN:9770972795006
Bark	Anti-infective agents, local	MESH:D000891, UM-LS:C0003205, ICD-11:XM4VG4	ISBN:81-204-0828-4, ISBN:9770972795006, ISBN:9780387706375
Bark, fruit, Leaves	Anti-inflammatory agents	MESH:D000893, UM-LS:C0003209, ICD-11:XM7XD1	ISBN:9788172360481, ISBN:9770972795006, Standardization of Single Drugs of Unani Medicine Part - IV
Bark, fruit, Leaves	Antinematodal agents	MESH:D000969, UM-LS:C0003391, ICD-11:XM16G5	ISBN:9770972795006

Plant part	Therapeutic use	Therapeutic use identifiers	References
Whole Plant	Antineoplastic agents	MESH:D000970, UMLS:C0003392	ISBN:9770972795006
Bark	Anti-obesity agents	MESH:D019440, UMLS:C0376607, ICD-11:5B81	ISBN:9770972795006
Bark	Antiprotozoal agents	MESH:D000981, UMLS:C0003416, ICD-11:XM4393	ISBN:9770972795006, ISBN:9788172360481
Bark	Antipyretics	MESH:D058633, UMLS:C0003419, ICD-11:XM1RS7	ISBN:9770972795006
Bark	Antitussive agents	MESH:D000996, UMLS:C0003449	ISBN:9770972795006
Plant exudate	Aphrodisiacs	MESH:D001046, UMLS:C0003567	ISBN:9788173717048
Bark, fruit, Leaves, plant exudate	Appetite stimulants	MESH:D019167, UMLS:C0376447	ISBN:9770972795006, ISBN:9780387706375, ISBN:9770972795006, ISBN:81-204-0828-4, ISBN:9770972795006, ISBN:9788172361266, ISBN:9788172363130, ISBN:9788173717048, Medicinal Plants of Nagpur And Wardha Forest Divisions (Maharashtra)
Bark, fruit, plant exudate	Asthma	MESH:D001249, UMLS:C0004096, DOI:2841, ICD-11:CA23	ISBN:9770972795006

Plant part	Therapeutic use	Therapeutic use identifiers	References
Bark, fruit, Leaves, whole plant	Astringents	MESH:D001252, UM- LS:C0004110, ICD-11:XM0VK6	ISBN:81-204-0828-4, ISBN:9770972795006, ISBN:9788172361266, ISBN:9789327275590, ISBN:9780387706375, ISBN:9788172361266, ISBN:9788172363130, Me- dicinal Plants of Nagpur and Wardha Forest Divisions (Ma- harashtra)
Leaves, plant exu- date	Blister	MESH:D001768, UM- LS:C1579830, ICD-11:ME63.3	ISBN:9770972795006
Fruit, Leaves	Bronchitis	MESH:D001991, UM- LS:C0006277, DOID:6132, ICD- 11:CA20	ISBN:9770972795006, ISBN:9788172360481
Bark	Cardiotonic agents	MESH:D002316, UM- LS:C0007209, ICD-11:XM91S1	ISBN:9770972795006
Seed	Chickenpox	MESH:D002644, UM- LS:C0008049, DOID:8659, ICD- 11:1E90.0	ISBN:9770972795006
Leaves	Cholestasis	MESH:D002779, UM- LS:C0008370, DOID:13580, ICD- 11:DC10.02	ISBN:9770972795006
Bark	Cholinester- ase inhibi- tors	MESH:D002800, UMLS:C0008425	ISBN:9770972795006
Leaves	Common cold	MESH:D003139, UM- LS:C0009443, DOID:10459, ICD- 11:CA00	ISBN:9770972795006
Leaves	Constipation	MESH:D003248, UM- LS:C0009806, DOID:2089, ICD- 11:ME05.0	Standardization of Single Drugs of Unani Medicine Part - IV

Plant part	Therapeutic use	Therapeutic use identifiers	References
Bark, fruit	Contraceptive agents	MESH:D003270, UMLS:C0009871	ISBN:9788172362300, ISBN:9770972795006
Bark, fruit, root	Cooling effect on body	UMLS:C0678568	ISBN:81-204-0828-4, ISBN:9788173717048
Leaves	Cough	MESH:D003371, UMLS:C0010200, ICD-11:MD12	ISBN:9770972795006, Standardization of Single Drugs of Unani Medicine Part - IV
Fruit, root, stem	Counterirritant	UMLS:C0010215	ISBN:9770972795006
Fruit	Cysts	MESH:D003560, UMLS:C0010709, ICD-11:EK70.Z	ISBN:9770972795006
Fruit	Delirium	MESH:D003693, UMLS:C0011206, ICD-11:6D70	ISBN:9770972795006
Plant exudate	Dermatitis	MESH:D003872, UMLS:C3875321, D01D:2723, ICD-11:EA8Z	ISBN:9770972795006
Bark	Dermatologic agents	MESH:D003879, UMLS:C0011625	ISBN:9770972795006
Bark, fruit, Leaves, plant exudate, root, seed, stem, whole plant	Diabetes mellitus	MESH:D003920, UMLS:C0011849, D01D:9351, ICD-11:5A14	ISBN:9770972795006, ISBN:9788171360536, ISBN:9788172362300, ISBN:9788172363130, ISBN:9788173717048, ISBN:9789327275590, ISBN:9788172361266, standardization of Single Drugs of Unani Medicine Part - IV
Bark	Diaphoretic	UMLS:C1707737	ISBN:9788172363130

Plant part	Therapeutic use	Therapeutic use identifiers	References
Bark, fruit, leaves, plant exudate, root	Diarrhea	MESH:D003967, UMLS:C0011991, D01D:13250, ICD-11:ME05.1	ISBN:9770972795006, ISBN:9788172362300, ISBN:81-204-0828-4, ISBN:9770972795006, ISBN:9780387706375, ISBN:9788173717048, Medicinal Plants of Nagpur and Wardha Forest Divisions (Maharashtra)
Bark, fruit, leaves, stem	Digestive system diseases	MESH:D004066, UMLS:C0012242, ICD-11:DE2Z	ISBN:9770972795006, ISBN:81-204-0828-4,
Whole plant	Disorder of ejaculation	UMLS:C0235969	ISBN:9789327275590, ISBN:9770972795006, ISBN:9788172360481
Fruit	Diuretics	MESH:D004232, UMLS:C0012798, ICD-11:XM4D06	ISBN:9770972795006
Fruit	Dizziness	MESH:D004244, UMLS:C0012833, ICD-11:MB48	ISBN:9770972795006
Leaves, plant exudate, root, stem, whole plant	Dysentery	MESH:D004403, UMLS:C0277526, D01D:12384, ICD-11:1A40.Z	ISBN:9770972795006, ISBN:9788171360536, ISBN:9789327275590, ISBN:9788172362300, ISBN:9788172363130, ISBN:9788173717048, Medicinal Plants of Nagpur and Wardha Forest Divisions (Maharashtra)
Bark, fruit	Dyspepsia	MESH:D004415, UMLS:C0013395, ICD-11:DD90.3	ISBN:9770972795006, ISBN:81-204-0828-4, ISBN:9780387706375, ISBN:9788171360536, ISBN:9788173717048, ISBN:9788172360481

Plant part	Therapeutic use	Therapeutic use identifiers	References
Bark, leaves, seed	Eczema	MESH:D004485, UMLS:C0013595	
Bark, fruit, plant exudate	Edema	MESH:D004487, UMLS:C0013604, ICD-11:MG29.1	ISBN:81-204-0828-4, ISBN:9770972795006
Whole plant	Epididymitis	MESH:D004823, UMLS:C0014534, D01D:9402, ICD-11:GB02.Y	ISBN:9789327275590, ISBN:9788172360481
Bark, fruit	Epistaxis	MESH:D004844, UMLS:C0014591, ICD-11:MD20	ISBN:9770972795006
Bark	Erysipelas	MESH:D004886, UMLS:C0014733, D01D:11330, ICD-11:1B70.0	ISBN:9770972795006
Leaves	Estrogen receptor modulators	MESH:D020847, UMLS:C0752229	ISBN:9770972795006
Fruit	Fatigue	MESH:D005221, UMLS:C0015672, ICD-11:MG22	ISBN:9770972795006
Bark	Female urogenital diseases	MESH:D052776, UMLS:C1720887	ISBN:9788172363130
Leaves, root	Fever	MESH:D005334, UMLS:C0015967, ICD-11:MG26	ISBN:9770972795006
Bark, fruit, leaves, whole plant	Flatulence	MESH:D005414, UMLS:C0016204, ICD-11:ME08	ISBN:81-204-0828-4, ISBN:9770972795006, ISBN:9788172361266, ISBN:9788172363130, ISBN:9788173717048, Medicinal Plants of Nagpur and Wardha Forest Divisions (Maharashtra), Standardization of Single Drugs of Unani Medicine Part - IV

Plant part	Therapeutic use	Therapeutic use identifiers	References
Plant exudate	Foot ulcer	MESH:D016523, UMLS:C0085119, ICD-11:FA11.Y	ISBN:9770972795006
Bark, leaves, plant exudate, whole plant	Furunculosis	MESH:D005667, UMLS:C0016867, ICD-11:1B75.0	ISBN:81-204-0828-4, ISBN:9770972795006, ISBN:9789327275590
Bark	Galactagogue	MESH:D056669, UMLS:C2717873	ISBN:9770972795006
Fruit, plant exudate	Gastric acid	MESH:D005744, UMLS:C0017119	ISBN:9770972795006
Flower, leaves	Gastrointestinal diseases	MESH:D005767, UMLS:C0017178, D011:DE2Z	ISBN:9770972795006
Bark, fruit, leaves, root	General tonic for rejuvenation	MESH:D012060, UMLS:C0035016	ISBN:9770972795006, Standardization of Single Drugs of Unani Medicine Part - IV
Bark	Genital diseases, female	MESH:D005831, UMLS:C0017411, ICD-11:GA6Z	ISBN:9770972795006
Bark, root	Gonorrhea	MESH:D006069, UMLS:C0018081, D011:7551, ICD-11:1A7Z	ISBN:81-204-0828-4, ISBN:9770972795006
Fruit	Headache	MESH:D006261, UMLS:C0018681, ICD-11:8A81.Z	ISBN:9770972795006
Seed	Hemagglutination	MESH:D006384, UMLS:C0018903	ISBN:9770972795006

Plant part	Therapeutic use	Therapeutic use identifiers	References
Bark, fruit, leaves	Hemoptysis	MESH:D006469, UM-LS:C0019079, ICD-11:MD22	ISBN:9788171360536, ISBN:81-204-0828-4, ISBN:9780387706375, ISBN:9788172361266, ISBN:9788172363130, ISBN:9788173717048, ISBN:9788171360536, Standardization of Single Drugs of Unani Medicine Part - IV
Bark, fruit	Hemorrhage	MESH:D006470, UM-LS:C0019080, ICD-11:MG27	ISBN:81-204-0828-4, ISBN:9770972795006, ISBN:9780387706375, ISBN:9788173717048
Bark, fruit, leaves, plant exudate	Hemorrhoids	MESH:D006484, UM-LS:C0019112, DOID:9746, ICD-11:DB60.Z	ISBN:9770972795006, ISBN:9788173717048, ISBN:9788172361266, ISBN:9788172363130, Medicinal Plants of Nagpur and Wardha Forest Divisions (Maharashtra), Standardization of Single Drugs of Unani Medicine Part - IV
Bark, leaf	Hemostasis	MESH:D006490, UMLS:C0019120	ISBN:9770972795006, Standardization of Single Drugs of Unani Medicine Part - IV
Leaves	Hoarseness	MESH:D006685, UM-LS:C0019825, ICD-11:MA82.10	Standardization of Single Drugs of Unani Medicine Part - IV
Whole plant	Hydrocele	MESH:D006848, UM-LS:C1720771, DOID:9912, ICD-11:GB00.Z	ISBN:9789327275590, ISBN:9770972795006, ISBN:9788172360481
Fruit	Hypercholesterolemia	MESH:D006937, UM-LS:C0020443, ICD-11:5C80.0	ISBN:9788172362300

Plant part	Therapeutic use	Therapeutic use identifiers	References
Root	Hypertension	MESH:D006973, UM-LS:C0020538, D0ID:10763, ICD-11:BA00.Z	ISBN:9770972795006
Bark, seed	Hypoglycemic agents	MESH:D007004, UMLS:C0020616	ISBN:9788172360481, ISBN:9788172362300
Fruit, leaves	Hypotension	MESH:D007022, UM-LS:C0020649, ICD-11:BA2Z	ISBN:9770972795006, ISBN:9788172360481
Fruit	Improve blood circulation	MESH:D001775, UMLS:C0005775	ISBN:9770972795006
Bark, fruit, plant exudate	Inflammation	MESH:D007249, UMLS:C0021368	ISBN:9770972795006
Fruit, leaves, root	Jaundice	MESH:D007565, UM-LS:C0022346, ICD-11:ME10.1	ISBN:9770972795006
Plant exudate	Kidney calculi	MESH:D007669, UM-LS:C0022650, ICD-11:GB70.0	ISBN:9770972795006
Leaves	Kidney diseases	MESH:D007674, UM-LS:C0022658, D0ID:557, ICD-11:GC2Z	Standardization of Single Drugs of Unani Medicine Part - IV
Whole Plant	Lactation disorders	MESH:D007775, UM-LS:C0022927, ICD-11:JB46.7	ISBN:9788172360481
Fruit, leaves, root	Laxatives	MESH:D054368, UM-LS:C0282090, ICD-11:XM62T3	ISBN:9770972795006, Standardization of Single Drugs of Unani Medicine Part - IV
Bark	Leprosy	MESH:D007918, UM-LS:C0023343, D0ID:1024, ICD-11:1B20	ISBN:9788171360536
Bark, fruit, leaves	Leukorrhea	MESH:D007973, UM-LS:C0023533, D0ID:3766, ICD-11:MF3A	ISBN:81-204-0828-4, ISBN:9770972795006, ISBN:9788172363130, ISBN:9780387706375

Plant part	Therapeutic use	Therapeutic use identifiers	References
Bark, leaves	Liver diseases	MESH:D008107, UM-LS:C0023895, D0ID:409, ICD-11:SA0Z	ISBN:9770972795006, ISBN:9788172361266, ISBN:9788172363130
Bark, fruit, plant exudate, reproductive organ, root, stem, whole plant	Lung diseases	MESH:D008171, UM-LS:C0024115, D0ID:850, ICD-11:CB40.Y	ISBN:9770972795006, ISBN:9789327275590
Whole plant	Lymphadenitis	MESH:D008199, UM-LS:C0024205, D0ID:1602, ICD-11:BD90	ISBN:9789327275590, ISBN:9770972795006, ISBN:9788172360481
Bark, stem	Malaria	MESH:D008288, UM-LS:C0024530, D0ID:12365, ICD-11:1F4Z	ISBN:9770972795006
Bark	Mastitis	MESH:D008413, UM-LS:C0024894, D0ID:10690, ICD-11:GB21.Z	ISBN:9770972795006
Bark, fruit, leaves, whole plant	Menorrhagia	MESH:D008595, UM-LS:C0025323, ICD-11:GA20.50	ISBN:81-204-0828-4, ISBN:9770972795006, ISBN:9789327275590, ISBN:9780387706375, ISBN:9788171360536, ISBN:9788172361266, ISBN:9788172363130, ISBN:9788173717048, Medicinal Plants of Nagpur and Wardha Forest Divisions (Maharashtra)

Plant part	Therapeutic use	Therapeutic use identifiers	References
Fruit, bark	Menstruation disturbances	MESH:D008597, UM-LS:C0025329, MESH:D008599, UMLS:C0025345, ICD-11:GA20.30	ISBN:9770972795006
Root	Mental disorders	MESH:D001523, UM-LS:C0004936, ICD-11:6E8Z	ISBN:9770972795006
Bark	Mouthwashes	MESH:D009067, UMLS:C0026647	ISBN:9770972795006
Plant exudate, root	Mumps	MESH:D009107, UM-LS:C0026780, D01D:10264, ICD-11:1D80	ISBN:9770972795006, ISBN:9788171360536
Fruit	Nervous system diseases	MESH:D009422, UM-LS:C0027765, D01D:863, ICD-11:8E7Z	ISBN:9770972795006
Bark	Nootropic agents	MESH:D018697, UMLS:C0242913	ISBN:9770972795006
Whole plant	Orchitis	MESH:D009920, UM-LS:C0029191, D01D:2518, ICD-11:GB02.Y	ISBN:9789327275590, ISBN:9770972795006, ISBN:9788172360481
Bark, fruit, leaves	Pain	MESH:D010146, UM-LS:C0030193, ICD-11:MG3Z	ISBN:81-204-0828-4, ISBN:9770972795006, Standardization of Single Drugs of Unani Medicine Part - IV
Bark, fruit	Peptic ulcer	MESH:D010437, UM-LS:C0030920, D01D:750, ICD-11:DA61	ISBN:9770972795006
Plant exudate	Periodontitis	MESH:D010518, UM-LS:C0031099, D01D:824, ICD-11:DA0C	ISBN:9770972795006
Bark, plant exudate	Pharyngitis	MESH:D010612, UM-LS:C0031350, D01D:2275, ICD-11:CA02.Z	ISBN:9770972795006
Bark, fruit	Polyuria	MESH:D011141, UM-LS:C0032617, ICD-11:MF55	ISBN:9770972795006

Plant part	Therapeutic use	Therapeutic use identifiers	References
Root	Rabies	MESH:D011818, UM-LS:C0034494, D01D:11260, ICD-11:1C82	ISBN:9770972795006
Bark	Salivation	MESH:D012472, UM-LS:C0036104, ICD-11:DA04.6	ISBN:9770972795006
Whole plant	Scabies	MESH:D012532, UM-LS:C0036262, D01D:8295, ICD-11:1G04	ISBN:9789327275590, ISBN:9770972795006, ISBN:9788172360481
Leaves	Scorpion stings	MESH:D065008, UM-LS:C0238417, ICD-11:NE61	ISBN:9770972795006
Root	Sexually transmitted diseases	MESH:D012749, UM-LS:C0036916, ICD-11:1A9Z	ISBN:9770972795006
Bark, plant exudate	Skin diseases	MESH:D017592, UM-LS:C0150773, MESH:D012871, UMLS:C0037274, D01D:37, ICD-11:EM0Z	ISBN:81-204-0828-4, ISBN:81-204-0828-4, ISBN:9770972795006, ISBN:9780387706375
Leaves	Smallpox	MESH:D012899, UM-LS:C0037354, D01D:8736, ICD-11:1E70	ISBN:9770972795006, ISBN:9788172360481
Bark, leaves, root	Snake bites	MESH:D012909, UMLS:C0037379	ISBN:9770972795006
Plant exudate, whole plant	Sprains and strains	MESH:D013180, UMLS:C0038048	ISBN:9770972795006, ISBN:9788172360481, ISBN:9789327275590
Fruit, leaves	Stomach diseases	MESH:D013272, UM-LS:C0038354, D01D:76, ICD-11:DA4Y	ISBN:9770972795006

Plant part	Therapeutic use	Therapeutic use identifiers	References
Plant exudate, bark	Stomatitis, aphthous	MESH:D013280, UM-LS:C0038362, D01D:9637, ICD-11:DA01, MESH:D013281, UMLS:C0038363, D01D:9663, ICD-11:DA01.10	ISBN:9770972795006
Bark, fruit	Syncope	MESH:D013575, UM-LS:C0039070, ICD-11:MG45.Z	ISBN:9770972795006
Bark, fruit	Excessive thirst	MESH:D013894	ISBN:81-204-0828-4, ISBN:9770972795006
Bark, plant exudate, stem	Toothache	MESH:D014098, UM-LS:C0040460, ICD-11:DA0A.Y	ISBN:9770972795006
Whole Plant	Tuberculosis	MESH:D014376, UM-LS:C0041296, D01D:399, ICD-11:1B1Z	ISBN:9770972795006
Bark, fruit, leaves, plant exudate	Ulcer	MESH:D014456, UMLS:C0041582	ISBN:81-204-0828-4, ISBN:9770972795006, ISBN:9780387706375, ISBN:9788172363130, ISBN:9788173717048
Bark, flower, fruit, root, stem	Urination disorders	MESH:D001744, UM-LS:C0005683, ICD-11:GB71.0, MESH:D014552, UM-LS:C0042029, D01D:0080784, ICD-11:GC08, MESH:D014555, UMLS:C0042035, ICD-11:GB0Y	ISBN:9770972795006, ISBN:9788173717048, ISBN:9788172363130
Bark, plant exudate	Urologic diseases	MESH:D014570, UMLS:C0042075	ISBN:81-204-0828-4, ISBN:9780387706375, ISBN:9770972795006
Bark, fruit	Vaginal diseases	MESH:D014623, UM-LS:C0042251, D01D:121, ICD-11:GA1Y	ISBN:81-204-0828-4, ISBN:9770972795006

Plant part	Therapeutic use	Therapeutic use identifiers	References
Bark, fruit, leaves, plant exudate	Vomiting	MESH:D014839, UMLS:C0042963, ICD-11:MD90.1	ISBN:9770972795006, ISBN:81-204-0828-4
Bark, leaves, plant exudate	Wound healing	MESH:D014945, UMLS:C0043240	ISBN:9770972795006, ISBN:9788172360481, Glimpses of Medico-Botany of Bastar District (M.P.)
Bark, fruit, leaves, plant exudate, root, stem	Wounds and injuries	MESH:D014947, UMLS:C0043251	ISBN:9770972795006, ISBN:9788173717048

Several studies have reported that *Ficus racemosa* possesses neuroprotective properties (Singh and Sharma, 2023; Rani et al., 2024). However, the therapeutic properties of *F. racemosa* in combating Parkinson's disease remain unknown. Therefore, the present study aims to investigate the unexplored therapeutic potential of *F. racemosa* in treating Parkinson's disease by exploring the genetic associations of its phytochemicals. Specifically, the study employed ADMET analysis, molecular docking, molecular dynamics simulations,

and interaction energy analysis via MMGBSA to elucidate how these phytochemicals could mitigate Parkinson's disease pathogenesis. Through these comprehensive computational approaches, the study seeks to provide a detailed understanding of the mechanisms by which phytochemicals of *F. racemosa* can exert their neuroprotective effects, potentially paving the way for novel therapeutic strategies against Parkinson's disease. The multidimensional computational methods used in this chapter were represented in Fig. 1.

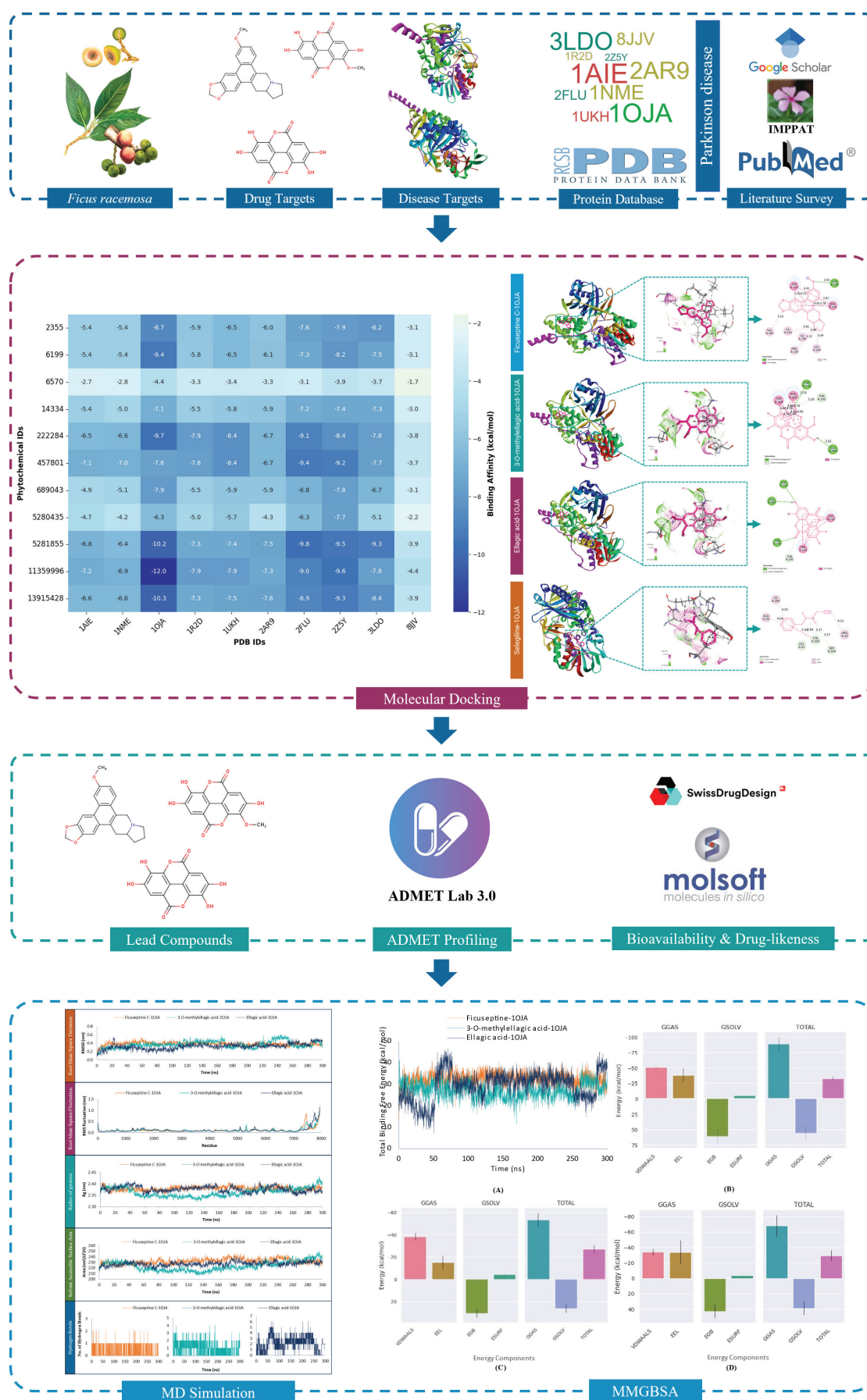


Fig. 1 General procedure of computational approaches

Materials and Methods

Assembling of Phytochemicals Library

All phytochemicals of *F. racemosa* were collected from the IMPPAT and Dr. Duke databases (Lans and van Asseldonk, 2020; Vivek-Ananth et al., 2023). Moreover, an extensive literature review was carried out to create a comprehensive library (Pahari et al., 2022; Rani et al., 2024). The PubChem database was utilized to obtain canonical SMILES, 3D structures, molecular weights, and PubChem CIDs for a thorough analysis (Kim et al., 2016). Canonical SMILES (simplified molecular input line entry system) notations were employed to evaluate the ADMET profiles (absorption, distribution, metabolism, excretion, and toxicity) of all phytochemicals and to screen potential lead compounds for drug-likeness and bioavailability. Moreover, three-dimensional structure was employed in molecular docking investigations, facilitating a comprehensive evaluation of compound characteristics, thereby advancing their potential as lead compounds in the development of drug.

Lipinski's Rule of Five

Canonical SMILES of phytochemicals were subjected to analysis based on Lipinski's rule of five parameters, including molecular weight (MW), hydrogen bond donors (nHD), hydrogen bond acceptors (nHA), and the octanol-water partition coefficient (LogP). Phytochemicals

not meeting Lipinski's rule of five criteria were classified as Lipinski violations (LV), while those meeting the criteria underwent molecular docking analysis (Lipinski, 2004).

Protein Data Extraction and Preparation

A total of 10 disease targets were selected for Parkinson's disease, according to comprehensive review of the literature (Du et al., 2020; Liu et al., 2021). The 3-D protein structure of genes was obtained from the protein data bank (Burley et al., 2017). The protein structure was modelled using MODELLER (version 10.5) and then optimized by adding missing residues and removing water molecules, co-ligands, and heteroatoms using UCSF ChimeraX software (version 1.7). Additionally, polar hydrogen atoms and charges were incorporated to ensure the optimal preparation of all target proteins for molecular docking (Meng et al., 2023).

Molecular Docking

Molecular docking was conducted to assess the interactions between phytochemicals and target proteins associated with a specific disease. The initial three-dimensional structures of both FDA-approved drugs and the screened phytochemicals were obtained from the PubChem database and used as ligands. The UCSF ChimeraX software was utilized to optimize protein structures by

adjusting unfavourable torsional angles and modifying nonstandard residues. This process effectively reduced energy and ensured structural stability (Meng et al., 2023). The optimization process improved the binding of ligands to receptor molecules, effectively preventing steric clashes. Molecular docking analyses were performed using AutoDock Vina, a widely used software for predicting ligand-protein interactions. Ligand energy minimization and the conversion of receptor-ligand complexes from pdb to pdbqt format were performed using Open Babel, a powerful toolkit for molecular modelling (Butt et al., 2020; Chaurasia et al., 2023). Blind docking was conducted by enlarging the grid box to encompass the protein structure. Evaluating the binding affinities between the ligand and protein included analysing docking scores (in kcal/mol) and relative mean square deviation (RMSD). Afterwards, protein-ligand complexes were analysed and visualized using Discovery Studio 2021 Client software.

ADMET Profiling of Lead Compounds

In the absorption, distribution, metabolism, excretion, and toxicity (ADMET) profiling, parameters including P-glycoprotein inhibition (pgp_{inh}) and substrate (pgp_{sub}), human intestinal absorption (HIA), fraction unbound in plasma (fu), plasma protein binding (PPB), drug metabolism-related parameters such as inhibition (inh) and substrate (sub) for CYP2C9, CYP2C19, and CYP3A4, CYP2C8 inh as well as plasma clearance (cl-plasma), elimination half-

life ($t_{0.5}$), hematotoxicity, neurotoxicity, and oxidative stress-antioxidant response element (SR-ARE) were taken into account (Balkrishna et al., 2023). Compounds meeting all criteria within the medium range of empirical decisions as per ADMETlab 3.0 were chosen for further analysis.

Lead Compounds Drug Profiling

All compounds were evaluated for their drug-likeness (DL) and oral bioavailability (OB) to identify potential leads. Drug-likeness refers to the degree of similarity between a compound's chemical structure and that of well-known drugs. Oral bioavailability relates to the amount of medication administered orally that reaches the bloodstream and impacts local tissues and organs before producing a similar pharmacological effect (Ahmed et al., 2022). The therapeutic potential of phytochemicals is evaluated based on their DL and OB, with screening thresholds set at ≥ 0.18 for DL and ≥ 0.30 for OB, analysed respectively using Molsoft L.L.C. and the SwissADME tool (Daina et al., 2017).

Molecular Dynamics Simulation

The molecular dynamics (MD) simulation was performed using GROMACS software, version 2023.3, within a Linux environment. For the simulation, the force fields used were the CHARMM36 force field for the protein structure and the CHARMM all-atom force field for ligand parameterization (Valdés-Tresanco et al., 2021). The system was prepared for

simulation using the TIP 3-point solvent model for solvation, followed by neutralization with the addition of (0.1M) of Na⁺ and Cl⁻ ions. Energy minimization was performed using the steepest descent algorithm for 50,000 steps with a convergence criterion of 10.0 kJ/mol. The system was equilibrated in two phases: a 1000 ps NVT equilibration at 300K, followed by a 1000 ps NPT equilibration at 300K and 1 bar. The simulation used the leap-frog integrator with 150,000,000 steps, corresponding to 300 ns with a 2-fs time step. Energy data, log files, and coordinate data were saved every 100 ps. The post-simulation analysis covered several parameters, such as root mean square deviation (RMSD), root mean square fluctuation (RMSF), radius of gyration (Rg), hydrogen bonds (HB), and solvent accessible surface area (SASA). All MD simulation analyses utilized the integrated tools of GROMACS version 2023.3 (Balkrishna et al., 2023).

Binding Free Energy Analysis

We utilized the gmx_MMPBSA package (version 1.6.2) to compute the binding free

energy (ΔG) analysis on ligand-protein complexes. Binding free energy was analysed utilizing MM/GBSA (molecular mechanics/generalized born surface area) method (Valdés-Tresanco et al., 2021). The GROMACS trajectory, topology, and index files of the target complexes were employed in this methodology. The determination of the total binding free energy (ΔG_{total}) involved subtracting $\Delta G_{\text{receptor}}$ from $\Delta G_{\text{complex}}$, followed by subtracting ΔG_{ligand} from the obtained result. Subsequently, the data underwent analysis using the gmxMMPBSA ana module. The energy components such as changes in van der waals energy ($\Delta V_{\text{DWAAALS}}$), electrostatic (Coulombic) energy (ΔE_{EL}), generalized Born (GB) solvation energy (ΔE_{GB}), solvent-accessible surface area (SASA) term (ΔE_{SURF}), gas-phase free energy (ΔG_{GAS}), solvation free energy (ΔG_{SOLV}), and overall change in total free energy (ΔT_{TOTAL}) were analysed in the term of average value with standard deviation to assess the binding free energy.

Results and Discussion

Potential Phytochemical Profiling

Parkinson's disease presents a significant health challenge in aging populations and is primarily managed with dopamine therapy. Although this treatment approach is hindered by diminishing efficacy and the onset of dyskinesia, to impede disease progression

(Cai et al., 2024). Therefore, more therapeutic targets and treatment options need to be explored. Studies shown that *F. racemosa* is known for its diverse phytochemicals traditionally used for antioxidant and anti-inflammatory properties crucial in combating neurodegenerative processes (Rani et al., 2024) however, further exploration was needed. A total of 42 phytochemicals were

retrieved from various databases, along with an extensive literature survey. The obtained phytochemicals were screened based on Lipinski's rule of five and ADMET parameters (Table 2). After rigorous screening from the initial pool, only 11 phytochemicals met the

criteria for selection. These compounds were subsequently subjected to molecular docking analysis to evaluate their potential bioactivity and interaction profiles. These phytochemicals were specifically utilized in the molecular docking analysis.

Table 2 Screening of phytochemicals based on Lipinski's rule and ADMET

Phytochemical	Compound Id	MW	nHA	nHD	logP	LV	ADMET
Coumarin	323	146.04	2	0	1.47	0	NA
Gallic Acid	370	170.02	5	4	0.69	0	NA
Palmitic Acid	985	256.24	2	1	6.65	0	NA
Bergapten	2355	216.04	4	0	1.89	0	A
Psoralen	6199	186.03	3	0	1.75	0	A
Methyl vinyl ketone	6570	70.04	1	0	0.26	0	A
6-Hydroxy-4,4,7a-trimethyl-5,6,7,7a-tetrahydrobenzofuran-2(4H)-one	14334	196.11	3	1	1.51	0	A
Bergenin	66065	328.08	9	5	-1.31	0	NA
beta-Amyrin	73145	426.39	1	1	6.20	0	NA
alpha-Amyrin	73170	426.39	1	1	6.26	0	NA
Friedelin	91472	426.39	1	0	6.66	0	NA
Taraxerol	92097	426.39	1	1	6.69	0	NA
Cycloartenol	92110	426.39	1	1	8.11	0	NA
beta-Amyrin acetate	92156	468.4	2	0	6.55	0	NA
Lupeol acetate	92157	468.4	2	0	6.97	0	NA
Taraxerone	92785	424.37	1	0	6.44	0	NA
alpha-Amyrenyl acetate	92842	468.4	2	0	6.39	0	NA
Taraxasterol	115250	426.39	1	1	6.53	0	NA
2,3-Dimethylacrylic acid, (E)-	125468	100.05	2	1	1.04	0	NA
Campesterol	173183	400.37	1	1	7.65	0	NA
beta-Sitosterol	222284	414.39	1	1	8.11	0	A
Lanosterol	246983	426.39	1	1	7.43	0	NA
Lupeol	259846	426.39	1	1	7.22	0	NA
L-Arabinose	439195	150.05	5	4	-2.76	0	NA
Oleic Acid	445639	282.26	2	1	7.01	0	NA
Ferulic acid	445858	194.06	4	2	1.48	0	NA

Phytochemical	Compound Id	MW	nHA	nHD	logP	LV	ADMET
Clionasterol	457801	414.39	1	1	8.11	0	A
Caffeic Acid	689043	180.04	4	3	1.02	0	A
Bergaptol	5280371	202.03	4	1	1.71	0	NA
Phytol	5280435	296.31	1	1	7.23	0	A
Stigmasterol	5280794	412.37	1	1	7.29	0	NA
Rutin	5280805	610.15	16	10	-0.03	1	NA
Kaempferol	5280863	286.05	6	4	1.97	0	NA
(24E)-24-N-Propylidenecholesterol	5281328	412.37	1	1	7.48	0	NA
Ellagic Acid	5281855	302.01	8	4	0.95	0	A
2,3,8-Tri-O-methylellagic acid	5281860	344.05	8	1	1.86	0	NA
Sitogluside	5742590	576.44	6	4	4.65	0	NA
(-)-Ficuseptine C	11359996	347.15	4	0	3.73	0	A
beta-Sitosterol-d-glucoside	12309060	576.44	6	4	4.65	0	NA
3-O-methylellagic acid	13915428	316.02	8	3	1.21	0	A
5-Chloro-6beta-nitro-5alpha-cholestan-3-one	22296655	465.3	4	0	6.49	0	NA
{3S,5R,10S,13S,14S,17S}-4,4,10,13,14-Pentamethyl-17-[(E,2S)-6-methylhept-3-en-2-yl]-2,3,5,6,7,11,12,15,16,17-decahydro-1H-cyclopenta[a]phenanthren-3-ol	1.01E+08	426.39	1	1	7.05	0	NA

LogP: Partition coefficient; MW: Molecular weight; nH-A: H-bond acceptor; nH-D: H-bond donor; LV: Lipinski violations; A: Accepted; NA: Not Accepted

Molecular Docking Analysis

The molecular docking process utilized drug targets with disease-related targets corresponding to the 10 genes and 11 phytochemicals were docked with protein structures of key hub genes, including TP53, CASP3, MAPK8, SNCA, BCL2L1, CASP9, MAOA, NFE2L2, HSPA5 and MAOB identified by PDB IDs including 1AIE, 1NME, 1UKH, 8JJV, 1R2D, 2AR9, 2Z5Y, 2FLU, 3LDO and 10JA

respectively. The resulting interactions were visualized in a heat map, depicting affinity between phytochemicals and targeted proteins associated with the 10 genes, with darker colours indicating lower receptor-ligand affinity in kcal/mol (Fig. 2). The molecular docking interactions between selected bioactive compounds and the target protein monoamine oxidase B (MAOB) receptor with PDB ID: 10JA demonstrated varying degrees

of binding affinity and bond formation. The (-)-ficuseptine C with PubChem ID-11359996, exhibited the highest binding affinity at -12 kcal/mol, forming one hydrogen bond and a total of 15 bonds. The ligand 3-O-methylellagic acid (PubChem ID: 13915428) followed with a binding affinity of -10.3 kcal/mol, establishing 4 hydrogen bonds and the same total number of bonds as ficuseptine C. The ligand ellagic acid (PubChem ID: 5281855) showed a binding affinity of -10.2 kcal/mol, with 5 hydrogen bonds and a total of 16 bonds. In comparison, the

FDA-approved drug selegiline (PubChem ID: 26757) has a lower binding affinity of 6.6 kcal/mol, forming 3 hydrogen bonds and a total of 7 bonds. These variations indicated the potential effectiveness of these phytochemicals in targeting MAOB, with ficuseptine C showing the most promising interaction based on binding affinity (Table 3). The 3D and 2D structures of the targeted protein, along with the corresponding bonds formed during the interaction with neighbouring amino acids, were depicted in Fig. 3 A-D.

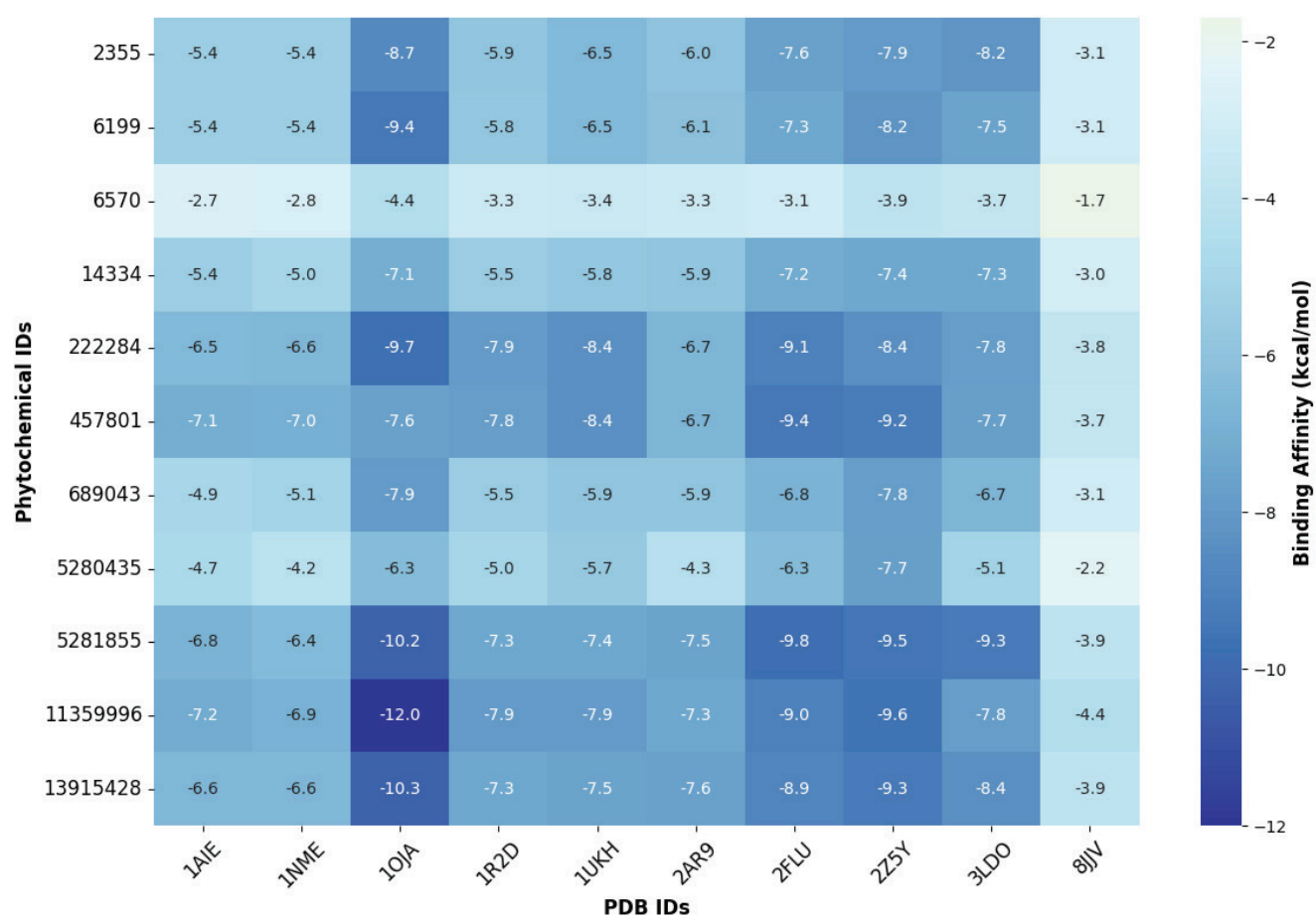


Fig. 2 Heat map of molecular docking illustrates interactions between phytochemicals and proteins linked to the top 10 hub genes

Table 3 Interactions between selected bioactive compounds and target proteins MAOB (10JA)

S.N.	Ligand	PubChem ID	Binding affinity (kcal/mol)	H-bonds	Total bonds	Type of Bond	Interacting residues	Bond Length (Å)
1	Ficuseptine C	11359996	-12	1	15	Conventional Hydrogen Bond	A:THR196:HG1-N:UNK1:O	2.55
						Pi-Pi Stacked	A:PHE103-N:UNK1	3.78
						Pi-Pi Stacked	A:PHE103-N:UNK1	4.92
						Pi-Pi Stacked	A:PHE103-N:UNK1	3.87
						Pi-Pi Stacked	A:TRP119-N:UNK1	3.69
						Pi-Pi Stacked	A:TRP119-N:UNK1	4.46
						Pi-Pi Stacked	A:TRP119-N:UNK1	4.02
						Pi-Pi Stacked	A:TRP119-N:UNK1	4.56
						Pi-Pi Stacked	A:TRP119-N:UNK1	6.00
						Pi-Pi Stacked	A:TRP119-N:UNK1	4.81
						Alkyl	A:PRO104-N:UNK1	5.12
						Alkyl	A:VAL106-N:UNK1	5.19
						Alkyl	A:LEU164-N:UNK1	4.39
						Alkyl	A:ILE199-N:UNK1	4.90
						Alkyl	A:ILE316-N:UNK1	4.85

S.N.	Ligand	PubChem ID	Binding affinity (kcal/mol)	H-bonds	Total bonds	Type of Bond	Interacting residues	Bond Length (Å)
2	3-O-Methyl-lagic acid	13915428	-10.3	4	15	Conventional Hydrogen Bond	A:THR196:HG1-N:UNK1:O	2.53
						Conventional Hydrogen Bond	N:UNK1:H-A:-GLU483:OE2	2.02
						Carbon Hydrogen Bond	A:THR195:HB-N:UNK1:O	3.10
						Carbon Hydrogen Bond	A:THR196:HA-N:UNK1:O	3.02
						Pi-Pi Stacked	A:PHE103-N:UNK1	3.74
						Pi-Pi Stacked	A:PHE103-N:UNK1	4.14
						Pi-Pi Stacked	A:PHE103-N:UNK1	4.65
						Pi-Pi Stacked	A:PHE103-N:UNK1	3.88
						Pi-Pi Stacked	A:TRP119-N:UNK1	4.15
						Pi-Pi Stacked	A:TRP119-N:UNK1	3.89
						Pi-Pi Stacked	A:TRP119-N:UNK1	5.03
						Pi-Pi Stacked	A:TRP119-N:UNK1	3.62
						Pi-Pi Stacked	A:TRP119-N:UNK1	5.38
						Pi-Pi Stacked	A:TRP119-N:UNK1	5.27
						Pi-Pi Stacked	A:TRP119-N:UNK1	4.05

S.N.	Ligand	PubChem ID	Binding affinity (kcal/mol)	H-bonds	Total bonds	Type of Bond	Interacting residues	Bond Length (Å)
3	Ellagic acid	5281855	-10.2	5	16	Conventional Hydrogen Bond	A:ASN116:HD21-N:UNK1:O	2.91
						Conventional Hydrogen Bond	A:THR196:HG1-N:UNK1:O	2.55
						Conventional Hydrogen Bond	N:UNK1:H-A:-GLU483:OE2	2.63
						Carbon Hydrogen Bond	A:THR195:HB-N:UNK1:O	3.08
						Carbon Hydrogen Bond	A:THR196:HA-N:UNK1:O	3.00
						Pi-Pi Stacked	A:PHE103-N:UNK1	4.14
						Pi-Pi Stacked	A:PHE103-N:UNK1	3.74
						Pi-Pi Stacked	A:PHE103-N:UNK1	3.88
						Pi-Pi Stacked	A:PHE103-N:UNK1	4.66
						Pi-Pi Stacked	A:TRP119-N:UNK1	3.88
						Pi-Pi Stacked	A:TRP119-N:UNK1	4.12
						Pi-Pi Stacked	A:TRP119-N:UNK1	3.63
						Pi-Pi Stacked	A:TRP119-N:UNK1	4.98
						Pi-Pi Stacked	A:TRP119-N:UNK1	5.25
						Pi-Pi Stacked	A:TRP119-N:UNK1	5.35
						Pi-Pi Stacked	A:TRP119-N:UNK1	4.04

S.N.	Ligand	PubChem ID	Binding affinity (kcal/mol)	H-bonds	Total bonds	Type of Bond	Interacting residues	Bond Length (Å)
4	Selegiline (FDA- approved Drug)	26757	-6.6	3	7	Carbon Hydrogen Bond	A:GLY41:HA2-N:UNK1:N	2.84
						Carbon Hydrogen Bond	N:UNK1:C-A:TYR393:O	3.17
						Carbon Hydrogen Bond	N:UNK1:C-A:SER394:OG	3.57
						Pi-Pi T-shaped Alkyl	A:TYR393-N:UNK1	5.34
							N:UNK1:C-A:ARG42	4.21
						Pi-Alkyl	N:UNK1-A:ALA35	4.04
						Pi-Alkyl	N:UNK1-A:ILE264	4.55

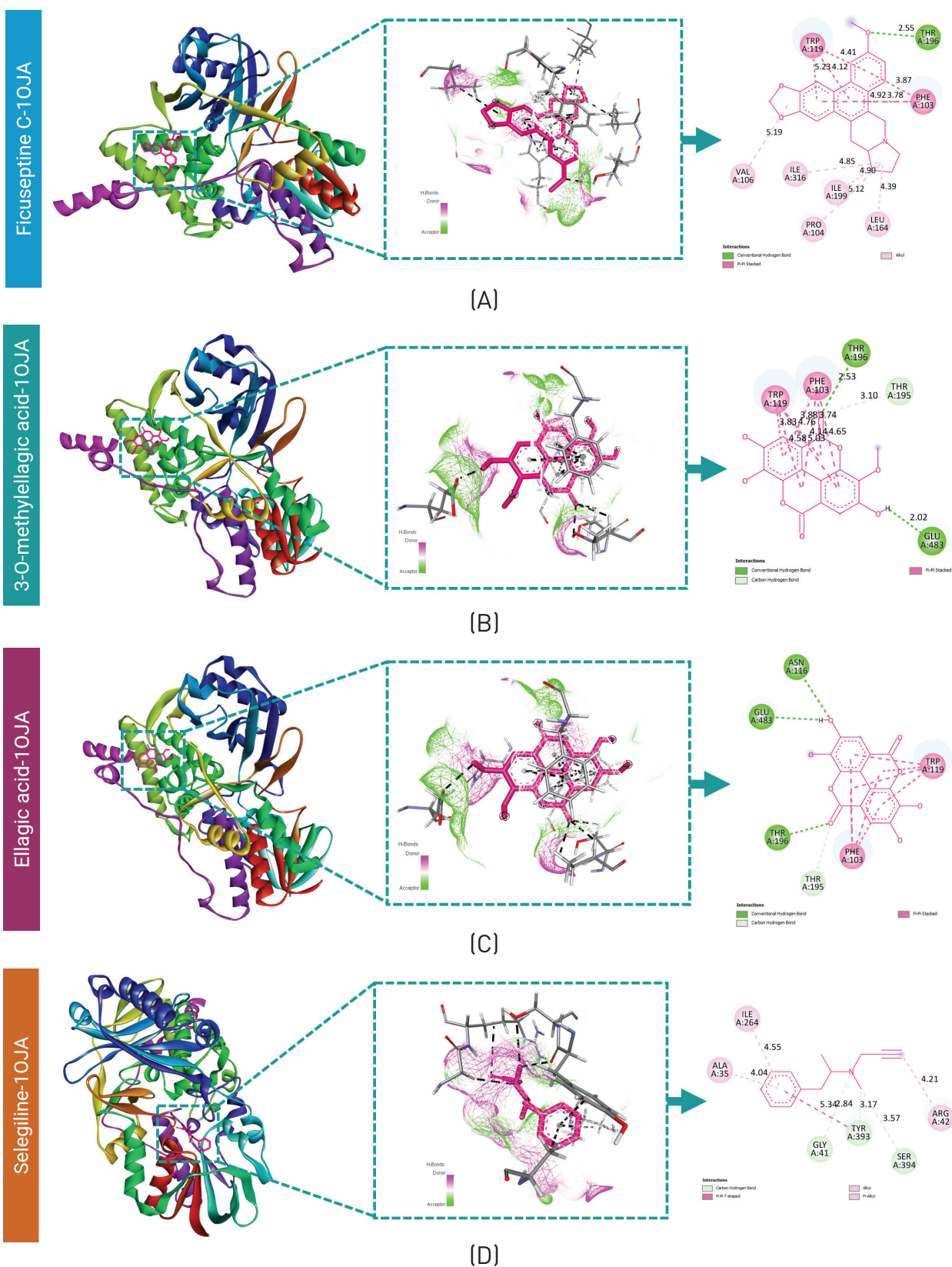


Fig. 3 (A-D) 3D and 2D structures of targeted protein docked with different phytochemicals. **(A)** ficuseptine C with the target protein 10JA **(B)** 3-O-methylellagic acid with the target protein 10JA **(C)** ellagic acid with the target protein 10JA **(D)** Selegiline (FDA-approved drug) with the protein 10JA

The result of current study aligns with previous research suggesting that ellagic acid treatment in PD models helps maintain dopaminergic neurons and dopamine transporter levels by reducing oxidative stress and inflammation. These results highlighted its neuroprotective potential, primarily through its antioxidant and anti-inflammatory properties (Ardah et al., 2020; Radwan et al., 2023). The ellagic acid has been reported to effectively protect against neurodegeneration in rats with Parkinson's disease by reducing oxidative stress and apoptosis, inhibiting MAOB activity, and preserving TH-positive neurons through the ERB/Nrf2/HO-1 signalling pathway (Baluchnejadmojarad et al., 2017). Moreover, the ellagic acid may serve as a therapeutic agent for Parkinson's disease by activating the Keap1-Nrf2-ARE signalling pathway and scavenging free radicals to reduce oxidative stress and neurodegenerative effects (Wang et al., 2022). Consistent with the docking results, a recent study highlighted the therapeutic promise of ellagic acid *via* experimental and computational methods. Molecular docking and dynamics simulations confirmed a stable formation of the human transferrin and ellagic acid complex, suggesting its neurodegenerative potential (Alrouji et al., 2024). Additionally, MAOB inhibitors were shown to be crucial in Parkinson's treatment, *via* molecular docking and molecular dynamic simulations. This provides valuable insights for PD drug development and aligning with the current study's identification of MAOB as a primary target (Azam et al., 2019). The ellagic acid

was shown to target rotavirus using network pharmacology, computational biology, and SPR verification. Molecular docking, MMGBSA, and molecular dynamics simulations confirmed strong ellagic acid binding to disease proteins and demonstrated remarkable binding affinity, consistent with the findings of the present study (Zheng et al., 2024). The ellagic acid provides neuroprotective benefits by inhibiting monoamine oxidase B, increasing neurotransmitter levels, reducing oxidative stress, modulating neuroinflammation, and promoting brain-derived neurotrophic factor expression, highlighting its potential in combating neurodegenerative diseases.

Drug Profiling of Lead Compounds

The pharmacokinetic properties, bioavailability, and drug-likeness of the lead compounds ficuseptine C, 3-O-methylellagic acid, and ellagic acid were comprehensively assessed for their suitability in drug development based on drug profiling results (Table 4). The analysis of ficuseptine C highlighted its moderate bioavailability (0.55) and drug-likeness score (0.34), affirming its potential as a lead compound in drug development. Similarly, 3-O-methylellagic acid and ellagic acid both had bioavailability scores of 0.55, but lower drug-likeness scores of 0.23 and 0.21, respectively. These findings suggest that while all three compounds possess favorable bioavailability, their drug-likeness varies, influencing their potential efficacy and development as therapeutic

agents. The ficuseptine C stands out for its superior drug-likeness among the compounds studied, making it a promising candidate for further pharmacological investigation and development. The findings emphasized the importance of comprehensive ADMET profiling in assessing lead compounds' pharmacokinetic and safety profiles for drug

development. These leading compounds also exhibited values below the moderate threshold for various ADMET parameters, including Pgp-inh, Pgp-sub, HIA, PPB, Fu, CYP2C19-inh, CYP2C19-sub, CYP2C9-inh, CYP2C9-sub, CYP2C8-inh, CYP3A4-sub, CL, T_{1/2}, hematotoxicity, neurotoxicity and SR-ARE (Table 5).

Table 4 Profiling of lead compounds for drug development

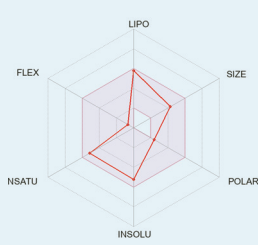
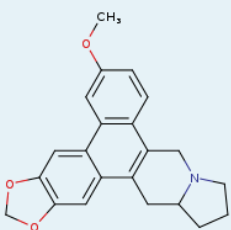
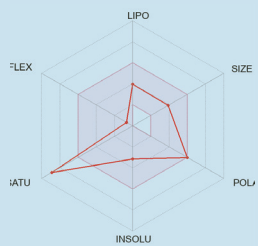
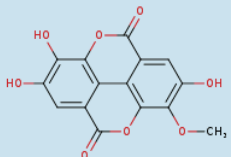
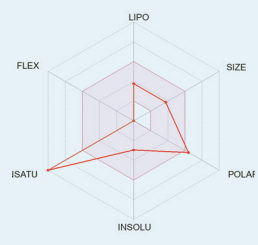
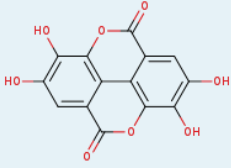
S. N.	Ligand	PubChem ID	Radar Chart	2D Structure	Bioavailability	Drug-likeness
1	Ficuseptine C	11359996			0.55	0.34
2	3-O-Methylellagic acid	13915428			0.55	0.23
3	Ellagic acid	5281855			0.55	0.21

Table 5 Characterization of lead compounds through ADMET profiling

Category	Parameter	Ficuseptine C	3-O-Methylelagic acid	Ellagic Acid
Absorption	pgp_inh	0.36	0.00	0.00
	pgp_sub	0.01	0.10	0.04
	hia	0.00	0.34	0.50
Distribution	PPB	88.01	82.37	68.54
	Fu	8.45	15.55	24.25
Metabolism	CYP2C19-inh	0.42	0.01	0.00
	CYP2C19-sub	1.00	0.00	0.00
	CYP2C9-inh	0.01	0.14	0.03
	CYP2C9-sub	1.00	0.94	0.56
	CYP3A4-inh	0.94	0.02	0.00
	CYP3A4-sub	0.16	0.00	0.00
	CYP2C8-inh	0.00	0.24	0.33
Excretion	cl-plasma	5.34	9.36	14.74
	t0.5	1.44	1.54	1.65
Toxicity	Neurotoxicity-DI	0.68	0.01	0.00
	Hematotoxicity	0.49	0.24	0.15
	SR-ARE	0.53	0.67	0.62

Structural Stability Analysis

Molecular dynamics simulations were conducted to examine the interactions between compounds and proteins at a molecular level. This study specifically focused on the interactions involving the binding of ficuseptine C, 3-O-methylelagic acid, and ellagic acid with monoamine oxidase B (PDB ID: 1OJA). Over a 300-nanosecond (ns) MD simulation, 3000 frames were analysed to evaluate the structural stability of the complexes, using parameters such as RMSD, RMSF, Rg, SASA, and HB.

Root Mean Square Deviation (RMSD)

The RMSD, a key metric in MD simulations for assessing the structural stability and fluctuations of biomolecular systems over time, was analysed for the backbone of three complexes including ficuseptine C-1OJA, 3-O-methylelagic acid-1OJA, and ellagic acid-1OJA. The ficuseptine C-1OJA had an average RMSD of 0.38 nm, ranging from 0.13 nm to 0.54 nm, with a standard deviation (SD) of 0.04 nm, indicating consistent structural stability with minimal fluctuations during the simulation. The 3-O-methylelagic acid-

10JA complex had an average RMSD of 0.37 nm, ranging from 0.11 nm to 0.60 nm, and an SD of 0.08 nm, suggesting slightly more variability but still relatively consistent behaviour with moderate fluctuations. The ellagic acid-10JA had the lowest average RMSD at 0.32 nm, ranging from 0.08 nm to 0.55 nm, and an SD of 0.07 nm, indicating a stable conformation with consistent backbone behaviour, demonstrating the highest structural stability among the three complexes. Overall, all three complexes showed remarkable structural stability, with ellagic acid-10JA being the most stable due to its lowest average RMSD and consistent behaviour (Fig. 4A).

Root Mean Square Fluctuation (RMSF)

The RMSF is pivotal metric in molecular dynamics for assessing atomic deviations from average positions over time. During MD simulation, ficuseptine C with 10JA maintained an average RMSF of 0.1 nm, indicating minimal atomic movement around mean positions, yet reached a maximum RMSF of 0.9 nm, highlighting specific areas of increased flexibility. Similarly, 3-O-methylellagic acid-10JA showed an average RMSF of 0.1 nm, implying stability with subtle fluctuations but revealed a higher maximum RMSF of 1.0 nm compared to ficuseptine C-10JA, suggesting more pronounced deviations in certain regions. The ellagic acid-10JA exhibited an average RMSF of 0.118 nm, slightly elevated compared to the others, indicating slightly

higher overall flexibility, with a maximum RMSF of 1.2 nm, signifying regions of significant atomic movement within its structure. In summary, ficuseptine C-10JA and 3-O-methylellagic acid-10JA complexes demonstrated comparable average RMSF values, implying similar overall stability with localized flexibility differences, while ellagic acid-10JA, while generally stable, displayed slightly more pronounced atomic fluctuations (Fig. 4B).

Radius of Gyration (Rg)

The Rg is a vital biophysical metric used to quantify the mass distributed around a molecule's centre or axis, providing crucial insights into its overall size and shape. The ficuseptine C, 3-O-methylellagic acid, and ellagic acid with 10JA revealed average Rg values of 2.38, 2.36, and 2.38 nm respectively, indicating similar compactness among these molecules with slight variations. Minimum and maximum Rg values showed the range of spatial distribution of ficuseptine C-10JA ranged from 2.35 to 2.41 nm, 3-O-methylellagic acid-10JA from 2.32 to 2.43 nm, and ellagic acid-10JA from 2.34 to 2.41 nm, highlighting their potential for structural flexibility. Standard deviations further clarified variability within each molecule type, with ficuseptine C, 3-O-methylellagic acid, and ellagic acid with 10JA at 0.01, 0.019, and 0.013 nm, respectively. These measures indicated that all the three complexes showed similar consistency in size and shape, crucial for understanding molecular dynamics and interactions (Fig. 4C).

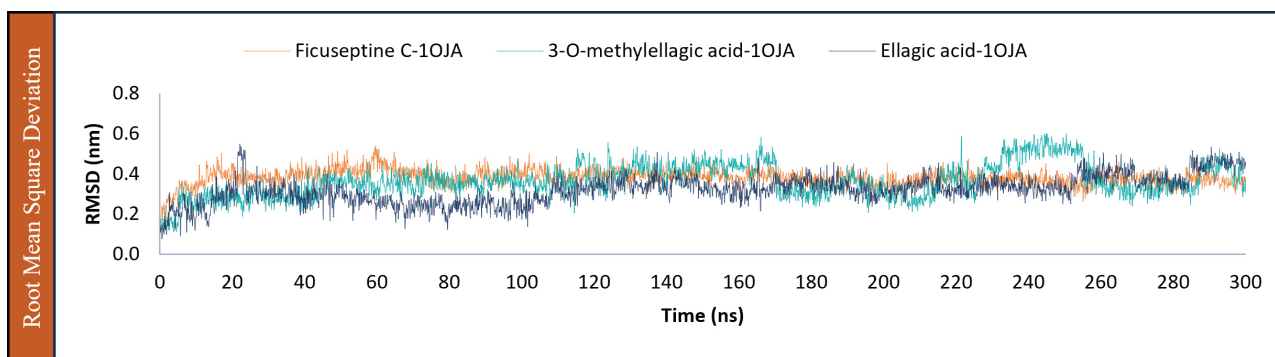
Solvent Accessible Surface Area (SASA)

The SASA is a fundamental metric in structural biology that how molecules interacted with their surroundings, including other molecules and solvents. The average SASA values of ficuseptine C, 3-O-methylellagic acid, and ellagic acid with 10JA were found 214.7, 223.3, and 227.2 nm² respectively, indicating similar extent of surface accessibility for each molecule, with variations reflecting differences in their molecular structure and composition. The standard deviations highlighted variability in molecular size, with ficuseptine C-10JA larger at 28.16 nm², 3-O-methylellagic acid-10JA smaller at 8.34 nm², and ellagic acid-10JA at 3.89 nm², emphasizing diverse molecular dimensions among the complexes. In general, all three complexes exhibited similarity in molecular sizes and shapes, with ficuseptine C showing greater variability due to its higher deviation (Fig. 4D).

5.4.5. Hydrogen Bonds (HB)

The analysis of hydrogen bond formation during MD simulations reveals significant differences in the interaction patterns of the three ligands

with the protein 10JA. The ficuseptine C with target protein 10JA formed a total of 362 hydrogen bonds, with 346 instances of a single hydrogen bond and 16 instances of two hydrogen bonds, indicating simpler and potentially weaker interactions (Fig. 4E). The 3-O-methylellagic acid formed 2161 hydrogen bonds with 10JA, including 1469 instances of a single hydrogen bond, 605 instances of two hydrogen bonds, 83 instances of three, and 4 instances of four hydrogen bonds. The 3-O-methylellagic acid formed more complex and stable interactions compared to ficuseptine C (Fig. 4F). The ellagic acid formed the highest number of hydrogen bonds with 10JA, totalling of 2735 including 594 instances of a single hydrogen bond, 970 instances of two hydrogen bonds, and 1171 instances of three or more hydrogen bonds. The ellagic acid showed the most stable and complex interactions, suggesting a high binding affinity and specificity (Fig. 4G). Among the three complexes, ellagic acid demonstrated the strongest and most complex interactions with 10JA, followed by 3-O-methylellagic acid, while ficuseptine C showed the least complex interactions.



(A)

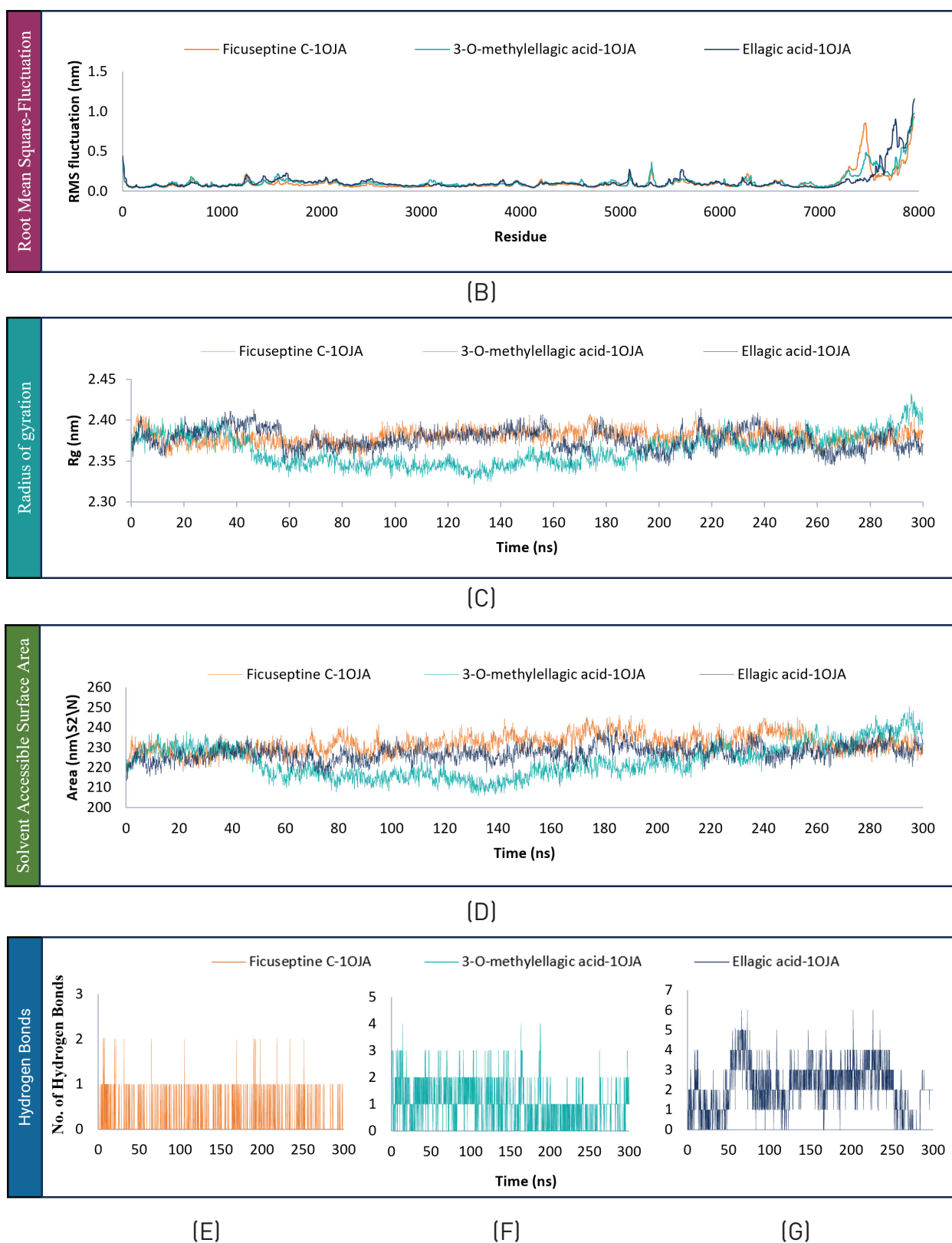


Fig. 4 (A-G) Molecular dynamics simulations endpoints as **(A)** Root Mean Square Deviation, **(B)** Root Mean Square Fluctuation, **(C)** Radius of Gyration (total and around axes), **(D)** Solvent Accessible Surface, **(E)** Hydrogen bond formed in ficuseptine C-1OJA **(F)** Hydrogen bond formed in 3-O-methylellagic acid-1OJA, and **(G)** hydrogen bond formed in ellagic acid-1OJA complex

In the current study, all three complexes demonstrated remarkable stability, with ellagic acid-10JA showing the lowest average RMSD and most consistent behaviour. Moreover, RMSF and Rg analyses indicated that all complexes maintained structural integrity with slight localized flexibility. A previous study utilizing molecular dynamics simulations demonstrated that ellagic acid effectively inhibits α -synuclein aggregation by significantly prolonging the lag phase and reducing the fibril growth rate. The RMSD analysis confirms the structural stability of ellagic acid-bound α -synuclein, aligning with the results obtained in the present study (Meena et al., 2021). The ellagic acid was shown to effectively disrupt α -synuclein fibril formation by targeting the non-amyloid- β component, as indicated by favourable binding free energy. Additionally, RMSF analysis revealed reduced flexibility near the binding site, aligning with our findings of present study (Mankoo et al., 2023). SASA results showed similar surface accessibility, with ficuseptine C exhibiting the most variability. Hydrogen bond analysis revealed ellagic acid formed the most complex and stable interactions, suggesting higher binding affinity and specificity.

Interaction Energy Analysis

The Binding Free Energy (BFE) trajectory analysis using MMGBSA provided insights into the interaction strength and stability of ficuseptine C, 3-O-methylellagic acid, and ellagic acid with Monoamine oxidase B (PDB ID: 10JA). The ficuseptine C-10JA had the strongest binding

affinity with an average BFE of -32.50 kcal/mol and a standard deviation (SD) of 2.98 kcal/mol, indicating consistent stability. Similarly, 3-O-methylellagic acid-10JA showed a slightly weaker binding affinity with an average BFE of -27.16 kcal/mol and an SD of 3.67 kcal/mol, reflecting moderate variability. The ellagic acid-10JA had an average BFE of -29.37 kcal/mol and the highest SD of 6.78 kcal/mol, indicating significant variability in binding stability (Fig. 5A). Despite non-significant differences among the complexes, ficuseptine C demonstrated the strongest and most consistent binding, making it the most promising candidate, while ellagic acid also showed strong binding and 3-O-methylellagic acid maintained stable interactions, highlighting their potential efficacy in targeting monoamine oxidase B.

In the comprehensive analysis of the binding free energy components for each complex, ficuseptine C-10JA demonstrated the most favourable binding free energy at -32.5 ± 2.98 kcal/mol. It had strong van der Waals interactions (-50.78 ± 2.46 kcal/mol) and electrostatic interactions (-37.93 ± 10.96 kcal/mol), though its polar solvation energy (61.18 ± 10.95 kcal/mol) was less advantageous. The non-polar solvation energy was -4.97 ± 0.2 kcal/mol. Its gas-phase energy was highly favourable (-88.71 ± 11.08 kcal/mol), offset somewhat by a less optimal solvation energy (56.21 ± 10.93 kcal/mol). Overall, ficuseptine C-10JA exhibited the strongest binding among the complexes studied (Fig. 5B). Moreover, 3-O-methylellagic acid-10JA had the least favourable binding free energy at -27.16 ± 3.67 kcal/mol. It showed weaker van der Waals

(-38.36 ± 3.17 kcal/mol) and electrostatic interactions (-15.19 ± 6.08 kcal/mol). Its polar solvation energy was more beneficial (30.61 ± 3.81 kcal/mol), and non-polar solvation energy was -4.22 ± 0.28 kcal/mol. The gas-phase energy was least favourable (-53.55 ± 6.11 kcal/mol), but it had the most advantageous solvation energy (26.39 ± 3.71 kcal/mol). Despite these factors, its overall binding free energy was substantial to maintain the stable interaction between ligand and receptor protein (Fig. 5C). Furthermore, ellagic acid-10JA had a total binding free energy of

-29.37 ± 6.78 kcal/mol, with less favourable van der Waals interactions (-34.2 ± 4.19 kcal/mol) compared to ficuseptine C-10JA, with strong but uncertain electrostatic interactions (-33.94 ± 15.21 kcal/mol). Its polar solvation energy was less advantageous (42.72 ± 8.49 kcal/mol), while non-polar solvation energy was -3.95 ± 0.26 kcal/mol. The gas-phase energy was -68.14 ± 13.86 kcal/mol, and solvation energy was 38.77 ± 8.39 kcal/mol. The ellagic acid-10JA demonstrated moderately strong binding, balancing favourable and less optimal interactions (Fig. 5D).

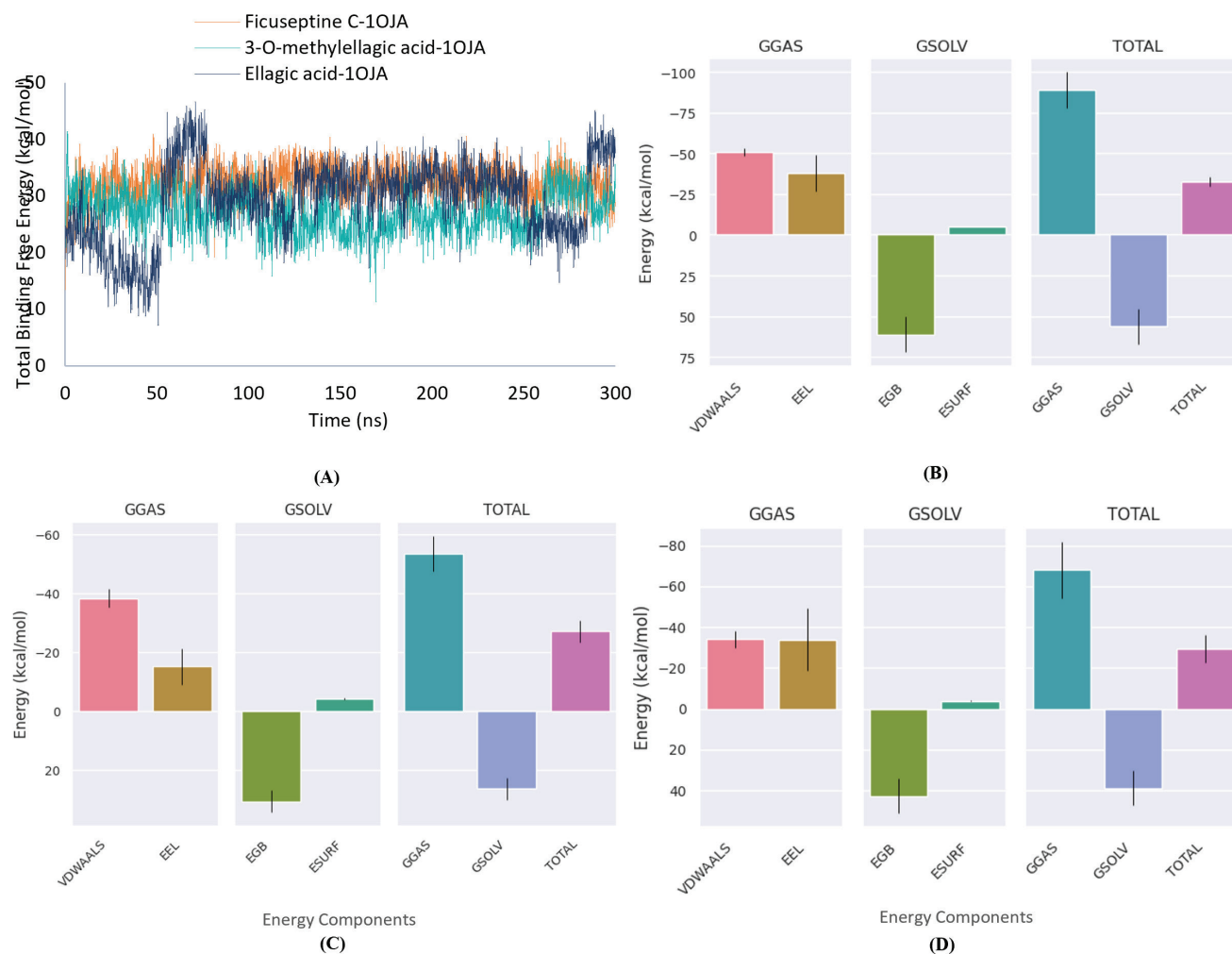


Fig. 5 (A) BFE trajectory of ficuseptine C-10JA, 3-O-methylellagic acid-10JA, and ellagic acid-10JA complexes. Binding Free Energy components of (B) ficuseptine C-10JA (C) 3-O-methylellagic acid-10JA, (D) and ellagic acid-10JA

The binding free energy is further decomposed into ΔG Complex, ΔG Receptor, and ΔG Ligand, with ΔG Total representing the cumulative energy of receptor-ligand binding. For the ficuseptine C-10JA complex, the ΔG Complex was -8044.91 kcal/mol, indicating a stable binding interaction, supported by a receptor contribution (ΔG Receptor) of -8020.63 kcal/mol. As a ligand, ficuseptine C contributed 8.21 kcal/mol (ΔG Ligand), resulting in a total binding free energy (ΔG Total) of -32.5 kcal/mol, indicating a strong overall binding affinity. Similarly, the 3-O-methylellagic acid-10JA complex exhibited a ΔG Complex of -7984.8 kcal/mol, with a prominent receptor-ligand interaction (ΔG Receptor of -8047.39 kcal/mol). As a ligand, 3-O-methylellagic acid contributed significantly with ΔG Ligand at 89.75 kcal/mol, resulting in a ΔG Total of -27.16 kcal/mol, indicating favourable binding. The ellagic acid-10JA complex showed a ΔG Complex of -7990.83 kcal/mol, with a receptor-ligand interaction (ΔG Receptor of -8039.26 kcal/mol). The ellagic acid contributed 77.8 kcal/mol (ΔG Ligand), resulting in a ΔG Total of -29.37 kcal/mol. In conclusion, all complexes demonstrated stable binding interactions

with varying degrees of ligand affinity, with 3-O-methylellagic acid displaying the strongest binding affinity based on its higher ΔG Ligand contribution (Table 6). In a similar study, ellagic acid (EA) disrupted α -Syn fibril stability primarily through interaction with the non-amyloid- β component (NAC), as evidenced by MMPBSA analysis that revealed a favourable binding free energy, suggesting its potential as an inhibitor of α -Syn fibrillization in Parkinson's disease (Mankoo et al., 2023). In another study, ellagic acid exhibited significant destabilization of A β fibrils through disruption of salt bridges and reduction in hydrogen bonds and β -sheet content, as supported by MM-PBSA analysis, highlighting its potential as a therapeutic agent for neurodegenerative disease (Gupta et al., 2020). Overall, ficuseptine C is the most promising candidate due to its strong and consistent binding affinity, followed by ellagic acid and 3-O-methylellagic acid, highlighting their potential efficacy in targeting monoamine oxidase B. Being of comparable structural stability and interaction energy analysis among all three studied compounds, they hold promise as potential therapeutic agents against Parkinson's disease.

Table 6 Net binding free energies of both the complexes (kcal/mol)

Complex	ΔG Complex	ΔG Receptor	ΔG Ligand	ΔG Total
ficuseptine C-10JA	-8044.91 $\pm$ 69.86	-8020.63 $\pm$ 69.69	8.21 $\pm$ 4.67	-32.5 $\pm$ 2.98
3-O-methylellagic acid-10JA	-7984.8 $\pm$ 75.58	-8047.39 $\pm$ 76.07	89.75 $\pm$ 3.97	-27.16 $\pm$ 3.67
ellagic acid-10JA	-7990.83 $\pm$ 74.88	-8039.26 $\pm$ 75.37	77.8 $\pm$ 4.5	-29.37 $\pm$ 6.78

Conclusion

This study investigated the unexplored therapeutic potential of *Ficus racemosa* phytochemicals in treating Parkinson's disease through comprehensive computational approaches. Out of 42 initial phytochemicals, 11 were selected based on Lipinski's rule of five and ADMET parameters. The findings of the study highlighted the significant binding affinities of ficuseptine C, 3-O-methylellagic acid, and ellagic acid with the monoamine oxidase B (MAOB) receptor, with ficuseptine C demonstrating the highest affinity. Pharmacokinetic profiling indicated ficuseptine C had the most favourable drug-likeness score, emphasizing its potential as a lead compound. Molecular dynamics simulations validated the structural stability of the phytochemical-MAOB complexes, with ellagic acid-10JA showing the highest structural stability due to highest number of hydrogen bond formed. Although, ficuseptine C and 3-O-methylellagic acid also exhibited remarkable structural stability during the 300 ns of MD simulation. Furthermore, ficuseptine

C showed the superior binding free energy and consistent stability during interaction energy analysis using MMGBSA, even though all three lead compounds exhibited stable binding interactions. Despite having non-significant differences in their structural stability and interaction energy parameters, all three studied compounds demonstrated remarkable therapeutic potential against Parkinson's disease. This indicates that, while the structural and energetic variations between the compounds were minimal, each one still exhibited a significant ability to combat the effects of Parkinson's disease effectively. Overall, this study provides compelling evidence for the therapeutic potential of *Ficus racemosa* phytochemicals, particularly ficuseptine C, 3-O-methylellagic acid, and ellagic acid, in treating Parkinson's disease. The results explore the way for further pharmacological investigation and development of *Ficus racemosa*-derived compounds as novel therapeutic strategies against PD.

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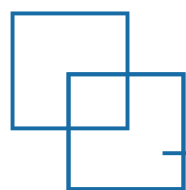
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CHAPTER 07

Reported Pharmacological Profile



INTRODUCTION

Since the beginning of time, medicinal plants have been employed as a source of medicine in almost all societies. The prevalence of natural substances with therapeutic capabilities has been linked to the usage of herbal medicines and healthcare items like those documented in ancient writings like the Vedas, the Bible which derived from widely utilized traditional herbs and medicinal plants (Ekor, 2014). With approximately 700 species spread out throughout the warmer regions of Asia, Africa, America, and Australia, the pan-tropical genus *Ficus* is incredibly large. It is kept as a single, large genus because of how distinctively it reproduces, using the synconia and specialized pollinator wasps (Di Giusto and Bain, 2024). The genus *Ficus* is an important group of trees which has various chemical constituents of promising medicinal value. *Ficus racemosa* is commonly known as the 'cluster fig' or 'goolar' in the Indian Traditional System of Medicine, belonging to the Moraceae family with various traditional uses and multiple pharmacological actions (Ahmed and Urooj, 2010). It is one of the popular plants in Indigenous system of medicine such as Ayurveda, Siddha, Unani, and homeopathy system of medicine. It is distributed widely from the outer Himalayan ranges, Punjab, Khasia Mountain, Chota Nagpur, Bihar, Orissa, West Bengal, Rajasthan, Deccan, and is common in South India (Paarakh, 2009). *F. racemosa* and other members of the genus *Ficus* has multiple pharmacological activities including analgesic, anthelmintic, anti-Alzheimer's, anti-asthmatic, anti-cancer, anti-cholinesterase, anti-diabetic, anti-diarrheal, anti-diuretic, anti-fertility, anti-hypertensive, anti-inflammatory, anti-microbial, antioxidant, anti-pyretic, anti-tussive, anti-thyroid, anti-quorum sensing, cardioprotective, cytotoxicity, effect on renal and testicular toxicity, effect on central nervous system, enzymatic, hepatoprotective, hypolipidemic, larvicidal, nephroprotective, radioprotective and wound healing actions. A brief review on the biological activity and therapeutic potential of *F. racemosa* is presented in this chapter.



Pre-Clinical Study

F. racemosa has been the subject of various preclinical studies to investigate its potential medicinal properties. Preclinical studies typically involve research conducted on animals or *in vitro* (outside the human body) to assess the safety and efficacy of a substance before moving on to human clinical trials. Further research, including human clinical trials, is typically needed to confirm these effects and determine safe and effective dosages for medicinal use. Here are some potential areas of study related to *F. racemosa*.

Analgesic, Anti-inflammatory and Anti-pyretic activities

Zulfiker et al. (2010) investigated the analgesic effect of ethanol extract (100 and 200 mg/kg, p.o.) of *F. racemosa* against acetic acid-induced writhing in Swiss albino mice by hot plate test. The extract showed an increase in latency time and percentage inhibitions of 50.14 and 56.56% at 90 min., respectively. The extract also exhibits a significant reduction ($p < 0.001$) of writhing in mice induced by acetic acid when compared to diclofenac sodium as reference drug.

Ferdous et al. (2008) evaluated the analgesic effect of ethanolic extracts (500 mg/kg, p.o.) of bark and fruits of *F. racemosa* against acetic acid induced writhing method in Swiss albino mice. The fruit extract showed most potent effect (61.38% inhibition, $p < 0.001$), whereas bark extract exerts least (42.76% writhing inhibition) when compared

to diclofenac sodium (75.17%) used as positive control.

Sunil and Priyanka (2010) determined the analgesic activity of petroleum ether, ethanolic, hydro-alcoholic extracts (100, 300 and 500 mg/kg, p.o.) of *F. racemosa* on acetic acid-induced writhing, hot plate methods in Swiss albino mice and, tail flick test in Wistar rats. The ethanolic and hydro-alcoholic extracts showed analgesic effect with 16.12 and 41.66% inhibitions of writhes at 500 mg/kg dose as compared to standard, aspirin (25 mg/kg) with 68% inhibition in treated mice. Both hydro-alcoholic and ethanolic extract resulted in a significant prolongation of latency time in hot plate test as well as, an increase in tail flick latency period except petroleum extract.

Rao et al. (2002) evaluated the anti-pyretic potential of methanol extract (100, 200 and 300 mg/kg, b.w. p.o.) from stem bark of *F. racemosa* against normal body temperature and yeast-induced pyrexia in albino rats. The extract dose-dependently lowered the body temperature and, also significantly decrease ($p < 0.001$ and $p < 0.01$) the rectal temperature in rats.

Chomchuen et al. (2010) reported the anti-pyretic activity of ethanolic extract (50-400 mg/kg) of *F. racemosa* root against lipopolysaccharides (LPS) and Brewer's yeast-induced fever in rats. Treatment with extract significantly ($p < 0.001$) reduced the increased rectal temperature produced by LPS as compared to acetylsalicylic acid (300 mg/kg)

as standard. The extract also significantly ($p < 0.05$) reduced the pyrexia induced by yeast as compared to standard.

Dharmadeva et al. (2018) demonstrated the anti-inflammatory activity of hot and cold-water extracts (0.01-1000 $\mu\text{g/ml}$) of *F. racemosa* bark against denaturation of egg albumin method. Both extracts showed higher inhibitory effect with IC_{50} values of 3691.97 and 4207.1 $\mu\text{g/ml}$ as compared to ibuprofen and prednisolone was 13,377.5 and 11,812.18 $\mu\text{g/ml}$, respectively used as reference drugs for tested method.

Mandal et al. (2000) evaluated the anti-inflammatory activity of petroleum ether extract (200 and 400 mg/kg) from *F. racemosa* leaves against carrageenan, serotonin, histamine, and dextran-induced hind paw edema in albino Wistar rats. The extract (400 mg/kg) exhibited maximum percentage inhibitions to be 30.4, 32.2, 33.9 and 32% at the end of 3 h with carrageenan, serotonin, histamine, dextran-induced rat paw edema when compared with phenylbutazone (100 mg/kg) used as standard with 39.7, 40.8, 42.1 and 39.1% inhibitions. In chronic test, the extract at highest dose attained 41.5% reduction in granuloma weight as compared to standard (49.7%).

Li et al. (2004) studied the anti-inflammatory activity of ethanolic extract along with isolated compound as racemosic acid from *F. racemosa* bark against COX-1 and 2, 5-LOX and phospholipase A_2 assay. The extract exhibited inhibitory effect with IC_{50} of 83.1 $\mu\text{g/ml}$ for COX-1 and, >1000 $\mu\text{g/ml}$ for

COX-2 enzymes. Further, the extract attained potent inhibitory effect of 58.5 $\mu\text{g/ml}$ on the formation of 5-HETE in 5-LOX assay. In PA_2 assay, the extract also inhibited the release of arachidonic acid from 1-stearoyl-2-[1- ^{14}C]-arachidonyl-L3-phosphatidylcholine with an IC_{50} value of 46.1 $\mu\text{g/ml}$ as compared to arachidonyl trifluoromethyl ketone (ATKetone) (12.2 μM) used as positive control. On the other hand, compound also showed potent effectiveness as 90 and 18 μM for COX-1 and 5-LOX as compared to indomethacin (9.5 and 65.2 μM) used as standard drug.

Li et al. (2003) evaluated the anti-inflammatory effect of ethanol extracts from inner bark, stem milky sap and frozen fruit of *F. racemosa* on cyclooxygenase-1 (COX-1) inhibition. The inner bark extract at 3.4 mg/ml dose showed potent percentage inhibition of 89.18%, followed by stem milky sap and frozen fruit extracts (71.26 and 44.53%) as compared to aspirin (0.3 mg/ml) and indomethacin (10 $\mu\text{g/ml}$) with 52 and 70% inhibitions used as positive controls on COX-1.

Anthelmintic Activity

Chandrashekhara et al. (2008) reported that the aqueous extract (50 mg/ml) of the bark exhibited anthelmintic effect on adult earthworms in a spastic paralysis model and like piperazine citrate (3%) used as standard drug. Further, the extract showed 100% spastic paralysis, whereas the worms came to a normal stage within 5 hours of standard treatment.

Anti-Alzheimer's Activity

Ahmed et al. (2011) demonstrated the anti-Alzheimer's activity of aqueous extract (250 and 500 mg/kg) of *F. racemosa* bark against acetylcholinesterase (AChE) levels and cognitive function using elevated plus-maze test in Wistar rats. The extract significantly ($p \leq 0.05$) enhanced the AChE level in hippocampi of rats. The percentage raise in Ach levels were found to be 22 and 38% at both doses of extract, respectively. Further, the extract at both doses elicited significant ($p \leq 0.05$) reduction in transfer latency for elevated plus-maze test in rats.

Anti-asthmatic Activity

Saleem and Byahatti (2019) performed the anti-asthmatic effect of petroleum ether, n-butanol, ethyl acetate and alcohol extracts (1, 10 and 100 mg/ml) of *F. racemosa* stem bark on histamine-induced contractions in albino guinea pigs. Both n-butanol and ethyl acetate extracts inhibited the histamine-induced contraction on guinea pig lung strip preparation.

Anti-cancer Activity

Gorla and Shankar (2016) performed the anti-cancer effect of ethanolic and n-hexane extracts (12.5-200 $\mu\text{g/ml}$) of dried powder leaves from *F. racemosa*. They reported that extracts exhibited percentage inhibitions as 18.60, 47.83% and, 16.94, 18.79% at 200 $\mu\text{g/ml}$, compared to cisplatin (95.97 and 60.45%) used as standard drugs against human lung

(A-549) and metastatic breast (MDAMB-435S) cancer cell lines using XTT assay.

Anti-cholinesterase Activity

Ahmed and Urooj (2010) evaluated the anti-cholinesterase activity of cold and hot aqueous extracts (200-1000 $\mu\text{g/ml}$) of *F. racemosa* stem bark against rat brain acetylcholinesterase. The hot extract showed significantly ($p \leq 0.001$) higher effectiveness in comparison to cold extract. However, both extracts showed inhibitory effect with values of 1813 and 1331 $\mu\text{g/ml}$, respectively.

Anti-diabetic Activity

Keshari et al. (2016) studied the anti-diabetic activity of flavonoids namely FR6, FR7, FR8 and FR9 (100 mg/kg, orally) isolated from stem bark of *F. racemosa* against streptozotocin (STZ)-induced diabetic albino Wistar rats. All tested flavonoids reduced blood glucose level and significant improvement of body weight and glycogen content in liver of treated rats. Further, all flavonoids exert reduction of other lipid profile parameters as well as an increase of high-density lipoprotein (HDL), while decreased SOD, CAT, GSH in pancreas and, TBARS and PC in liver.

Veerapur et al. (2012) reported the anti-diabetic activity of ethanol extract (200 and 400 mg/kg, p.o.) of *F. racemosa* stem bark against high-fat diet and low-dose streptozotocin (HFD+STZ) induced type 2 diabetic albino Wistar rats. Treatment with extract reduced blood glucose level, stimulation index,

homeostatic model assessment values as well as, decreased insulin resistance. The extract exhibits a significant ($p < 0.001$) reduction in TG, TC, VLDL-c and LDL-c levels and, increased HDL-c levels as well as, markers of dyslipidemia as compared to HFD+STZ diabetic rats. Further, the extract significantly ($p < 0.001$) prevented an increase in TBARS, SOD, catalase, GST, and total thiols levels with an improvement in GSH level. The extract at 200 $\mu\text{g/ml}$ dose exhibited 42.5% inhibition of DPP-IV and, PTP-1B ($\text{IC}_{50} = 12.1 \mu\text{g/ml}$). The extract exerts 82.6% binding to PPAR-c, while stimulation of glucose uptake by skeletal muscles (hemi-diaphragm).

Rao et al. (2002) demonstrated the anti-diabetic property of methanol extract (200 and 400 mg/kg p.o.) of bark of *F. racemosa* against normal and alloxan-induced diabetic albino Wistar rats. The extract at 200 mg/kg dose showed a significant effect ($p < 0.01$) with 19.82% reduction in glucose level whereas, maximum reduction of 40.33% in glucose level at 24 h after drug administration (400 mg/kg dose) was seen as compared to glibenclamide (43.76%) used as standard.

Joshi et al. (2016) investigated the anti-diabetic activity of ethanol extract (200 and 400 mg/kg) of *F. racemosa* bark against streptozotocin-induced diabetic albino Wistar rats. Treatment with extract markedly restores the blood glucose and lipid level ($p < 0.001$), and also reduced ($p < 0.00$) creatinine kinase, lactate dehydrogenase, C-reactive protein, creatinine, blood urea nitrogen, collagen and albumin levels as well

as, reduction in sodium, creatinine, albumin and MDA ($p < 0.01$) in heart and kidney tissue of treated rats along with enhancement of SOD ($p < 0.001$) and, reduced glutathione ($p < 0.001$). Moreover, left ventricular hypertrophic index and cardiac hypertrophic index were markedly reduced by extract.

Anti-diarrheal Activity

Patil et al. (2012) evaluated the anti-diarrheal effect of ethanol extract (400 and 600 mg/kg) of *F. racemosa* leaves against castor-oil induced diarrhea and PGE2-induced enteropooling in albino Wistar rats. The extract exerts significant reduction in fecal output and frequency of dropping in treated rats. The extract also significantly reduced ($p < 0.01$) diarrhea by inhibiting gastrointestinal motility and PGE2-induced enteropooling in rats as compared to atropine (0.1 mg/kg) used as standard.

Anti-diuretic Activity

Ratnasooriya et al. (2003) performed the anti-diuretic activity of aqueous bark decoction (250, 500 and 1000 mg/kg) of *F. racemosa* on urine output of albino rats. The decoction at both lower and higher doses impaired the total urine output in rats by 34 and 40%, while antidiuretic hormone (ADH) used as standard drug with 65% at 5 h of administration. The decoction also induced a significant impairment in urinary Na^+ level (56%), and Na^+/K^+ ratio (44%), respectively.

Anti-fertility Activity

Ahirwar et al. (2011) studied the anti-fertility activity of hydro alcoholic extract (50 mg/kg for 30 d; 100 mg/kg for next 30 d) from *F. racemosa* bark on reproductive organs and fertility of Swiss mice. The extract showed a 70% reduction in fertility within 60 d and, suppression of cauda epididymis sperm count, motility, viability, and abnormal morphology. Moreover, there was a significant reduction ($p < 0.05$) in weight of reproductive organs and the level of sialic acid in epididymis as well as, fructose in seminal vesicle. Vaginal application of bark extract exhibited 80% vaginal contraceptive efficacy, while extract altered parameters recovered after 60 d.

Anti-hypertensive Activity

Ahmed et al. (2010) studied the angiotensin converting enzyme (ACE) inhibitory activity of cold and hot aqueous extracts of *F. racemosa* stem bark using rabbit lung and partially purified porcine kidney ACE. The hot extract showed a significantly higher ($p \leq 0.01$) effect than cold extract with lower IC_{50} values of 1.36 and 1.91 $\mu\text{g/ml}$ for porcine kidney and rabbit lung ACE, when compared with cold extract (128 and 291 $\mu\text{g/ml}$).

Anti-microbial and Anti-Quorum Sensing Activities

Bopage et al. (2018) performed the anti-microbial activity of ethyl acetate, methanol, hexane, and dichloromethane extracts of stem bark of *F. racemosa* against *Bacillus subtilis*,

Escherichia coli, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Saccharomyces cerevisiae* (NCYC 2401 and 2402), *Saccharomyces sp.* and *Candida albicans* using disc-diffusion method. Only ethyl acetate and methanol extracts exhibited zone inhibitions as 10.44, 10.50 mm and, 9.63, 9.56 mm against *B. subtilis* and *S. aureus* when compared with positive control, amoxicillin (12.13 and 11.44 mm), followed by 10.69, 8.38, 9.38 and 10.69 mm and 10.38, 7.31, 8.94 and, 9.94 mm towards fungal strains as compared to positive control, polymyxin B (12.12, 11.44, 9.38 and 12.13 mm) whereas, other extracts did not show any effect for tested strains.

Mandal et al. (2000) evaluated the anti-bacterial activity of petroleum ether, benzene, chloroform, acetone, methanol, and water extracts (25 mg) of *F. racemosa* leaves against *Escherichia coli*, *Bacillus pumilis*, *B. subtilis*, *Pseudomonas aeruginosa* and *Staphylococcus aureus* using agar diffusion method. All extracts exhibited anti-bacterial effect with zone inhibitions ranging from 8 to 20 mm as compared to chloramphenicol used as standard (20-30 mm) for tested strains.

Hossain et al. (2014) studied the anti-microbial effect of methanol extract (100, 150 and 200 $\mu\text{g/disc}$) of *F. racemosa* fruits against *Staphylococcus aureus*, *Bacillus subtilis*, *Vibrio cholera*, *Bacillus cereus*, *Salmonella typhi*, *Shigella dysenteriae*, *Pseudomonas aeruginosa*, *Klebsiella* species using disc-diffusion method. The extract at 200 $\mu\text{g/disc}$ showed highest zone inhibition which was 18 mm for *S. aureus* whereas, other strains were found effective

from 15-17 mm as compared to kanamycin (24 to 32 mm) used as standard.

Namasivayam et al. (2020) evaluated the anti-quorum sensing activity of ethanol extract (10, 25, 50, 75 and 100 mg/ml) from powder of *F. racemosa* stem bark against clinical isolate of *Pseudomonas aeruginosa* and violacein pigment producing *Chromobacterium violaceum*. The extract exhibited inhibitory effect with MIC value of 43.3 mg/ml for *P. aeruginosa*. Further, the extract also exerts drastic reduction of all tested virulence factors and AHL production. At 100 mg/ml of extract showed zone inhibition of 20.3 mm against *C. violaceum*.

Antioxidant Activity

Veerapur et al. (2009) assessed the antioxidant property of ethanol (FRE) and water (FRW) extracts of bark of *F. racemosa* using DPPH, ABTS, hydroxyl radical (OH), superoxide radical ($O_2^{\bullet-}$) and lipid peroxidation (LPO) assays. FRE exhibited DPPH and ABTS scavenging effect with IC_{50} values of 5.99 and 4.29 μ g/ml as compared to ascorbic acid (2.78 μ g/ml) used as standard. The FRE extract exhibit better effectiveness of LPO inhibition with 0.61 μ g/ml when compared with trolox (7.99 μ g/ml) used as standard, followed by FRW of 190.61 μ g/ml. In addition, FRE attained better OH scavenging effect with 59.08 μ g/ml than mannitol (2.95 μ g/ml) as standard. However, FRE also exhibited scavenging of ($O_2^{\bullet-}$) with 66.88 μ g/ml as compared to BHA (1.46 mg/ml).

Jahan et al. (2009) evaluated the antioxidant effect of parent extract (FRp), 1-butanol soluble

extract (FR-3), its fractions (FR-3-2, FR-3-4, FR-3-6, FR-3-7, FR-3-8, FR-3-2-4, FR-3-2-4-5) along with 3-O (E)-caffeoyl quinate isolated from *F. racemosa* fruits using DPPH assay. All fractions attained good effectiveness ranged from 80 to 94.88% for DPPH, whereas compound exhibit most potent scavenging effect with 95.10% inhibition as compared to propyl gallate (94%) used as standard.

Ahmed et al. (2010) reported the antioxidant activity of hot and cold aqueous extracts of stem bark of *F. racemosa* using DPPH assay. Both extracts (25 μ g/ml) showed good radical scavenging effect with maximum inhibitions were 87 and 75% when compared to butylated hydroxytoluene (BHT) (73%) used as positive control.

Khan et al. (2017) reported the antioxidant effect of ethanolic extract from leaves of *F. racemosa* using DPPH, FRAP, nitric oxide and superoxide scavenging assays. The extract exhibited scavenging effect with IC_{50} values of 150 μ g/ml for DPPH and, 100 μ g/ml for NO and SO scavenging assays. In FRAP assay, the extract at concentration ranged from 25 to 200 μ g/ml showed a significant increase in absorbance with 0.23, 0.34, 0.46, 0.56 and 0.63 at 700 nm.

Anti-thyroid Activity

Azharuddin et al. (2015) demonstrated the anti-thyroid potential of ethanolic extract (250, 350 and 450 mg/kg; oral) of bark of *F. racemosa* against thyroxine-induced in albino Wistar rats. The extract decreases the increased levels of triiodo-L-thyronine

and L-thyroxine as well as, decrease in T3 and T4 levels as compared to methimazole used as reference drug.

Anti-tussive Activity

Rao et al. (2003) reported the anti-tussive activity of methanol extract (100 and 200 mg/ml) of *F. racemosa* stem bark against sulphur dioxide (SO₂)-induced cough model in albino mice. The extract at 200 mg/kg dose produced maximum inhibition of cough (56.9%) after 90 min. in treated mice as compared to codeine phosphate (10 mg/kg) used as standard with 62.9% inhibition.

Cardioprotective Activity

Ahmed and Urooj (2012) studied the cardioprotective activity of petroleum ether, chloroform, acetone, methanol, and water extracts (250 and 500 mg/kg) of *F. racemosa* stem bark against doxorubicin-induced toxicity in Wistar rats. The extract significantly ($p \leq 0.01$) attenuated an increase in LDH value while, the activity of CK-MB was decreased. Pre-treatment with extract significantly ($p \leq 0.05$) decreased TBARS value but increased glutathione levels in serum and cardiac tissue.

Cytotoxicity

Khan et al. (2017) reported the cytotoxicity of ethanolic extract of leaves of *F. racemosa* against Dalton Lymphoma ascites (DLA) cell line by MTT assay. The extract showed cytotoxic effect with IC₅₀ value as 175 µg/ml for DLA cell.

Effects on Central Nervous System (CNS)

Munira et al. (2018) investigated the effect of methanol extract of *F. racemosa* on CNS of albino Swiss mice using open field and hole cross tests as well as, forced swimming and tail suspension methods. The extract at 400 mg/kg significantly reduced the number to 76.25, 68, 53 and 27 after 30, 60, 90 and 120 min., respectively in open field test. In the hole cross test, the extract exhibited a decrease in the movements of tested animals at all dose levels tested. The extract showed immobility time was higher than control in forced swimming and tail suspension tests.

Effects on Renal and Testicular Toxicity

Ahmed et al. (2012) evaluated the protective effect of sequential acetone extract (250 and 500 mg/kg, p.o.) of *F. racemosa* bark against doxorubicin-induced renal and testicular toxicity in Wistar rats. The extract at 500 mg/kg exhibited significantly higher ($p \leq 0.05$) protein restoration effect than at 250 mg/kg. Further, the extract at both doses decreased serum creatinine levels by 22.5 and 44%, while serum urea levels were decreased by 30.4 and 58.8%, respectively. In addition, the extract highest dose decreased TBARS but, increased glutathione levels in the kidney and testis to control levels.

Enzyme Inhibitory Activity

Binh et al. (2016) assessed the enzyme inhibitory activity of ethanol and water

extracts of *F. racemosa* against α -glucosidase and α -amylase inhibitory assay. In α -amylase inhibition assay, only ethanol extract showed potent effect with IC_{50} value of 46.7 μ g/ml as compared to water extract (742.7 μ g/ml). Also, the ethanol extract attained effectiveness at 278.6 μ g/ml for α -glucosidase assay.

Ahmed and Urooj (2010) evaluated the enzyme inhibitory activity of untreated and heat-treated stem bark of *F. racemosa* (FRB) on carbohydrate hydrolyzing enzymes viz., porcine pancreatic α -amylase, rat intestinal α -glucosidase, sucrose, and almond β -glucosidase enzymes. Untreated FRB showed inhibitory effect with IC_{50} values of 280, 212 and 367 μ g/ml for α -glucosidase, β -glucosidase, and sucrose, while 259, 223 and 239 μ g/ml for heat treated FRB. However, both untreated and heat-treated FRB exhibit 0.94 and 0.58% inhibition on α -amylase enzyme.

Koli et al. (2022) investigated the enzymatic effect of methanol (FR-50) and water extracts (FR-70) of *F. racemosa* leaves (2-10 mg/ml) against ruminal glutamic oxaloacetic transaminase (R-GOT) and glutamic pyruvic transaminase (R-GPT). Both FR-70 and FR-50 inhibited R-GOT (protozoal) more effectively with EC_{50} of 17.17 and 12.33 mg/ml, but they were less active against R-GOT bacterial fraction with relatively higher values of 19.17 and 16.33 mg/ml. In addition, FR-50 exhibit significantly ($p < 0.05$) higher inhibition in GPT activity than FR-70 in both protozoal and bacterial fractions. The FR-50 inhibits 50% of cellulase activity at 9.70 mg/ml whereas, FR-70 exert value of 24.72 mg/ml. In addition, FR-

50 more potently inhibited R-GDH protozoal fraction activity as well as, inhibited R-GDH activity at 10 mg/ml, R-GDH (bacterial fraction) at 14 mg/ml. However, there was a decrease of 20–30% and 18–20% in protease activity by FR-50 and FR-70 fractions.

Gorla and Shankar (2016) performed the enzyme inhibitory effect of ethanolic and n-hexane extracts (3.125-100 μ g/ml) of *F. racemosa* against pancreatic lipase enzyme. Both extracts showed maximum inhibition with 66.09 and 97.85% at 100 μ g/ml for lipase enzyme as compared to orlistat (77.56%) used as standard.

Hepatoprotective Activity

Ahmed and Urooj (2010) evaluated the hepatoprotective activity of petroleum ether (FRPE) and methanol extracts (FRME) of stem bark of *F. racemosa* against carbon tetrachloride-induced hepatic damage in albino rats. Pre-treatment with FRPE and FRME restored total protein and albumin to near normal levels. Treatment with both extracts decreased in activities of AST, ALT and ALP when compared to CCl_4 -treated rats. Also, decreased total bilirubin content (0.8 and 0.3 mg/dL) in CCl_4 -treated rats. The extracts improved antioxidant status considerably as reflected by low TBARS and high GSH values.

Mandal et al. (1999) reported the hepatoprotective activity of petroleum ether extract (400 mg/kg, p.o.) of *F. racemosa* leaves against carbon tetrachloride (CCl_4)-induced chronic liver damage in albino rats. The extract at tested dose exhibited reduction in CCl_4 -

induced increase in the levels of SGOT, SGPT, alkaline phosphatase and serum bilirubin in treated rats.

Solanki et al. (2021) evaluated the hepatoprotective effect of methanolic extract (100-400 mg/kg; p.o.) of *F. racemosa* bark on high-fat-high-fructose (HFHF) diet-induced non-alcoholic fatty liver disease (NAFLD) in Wistar rats. The extract significantly ($p < 0.05$) reduced MDA, AST, ALT, TG, TC, LDL, and VLDL levels as well as, reduction in serum leptin and fatty changes. The extract also exhibited a significant ($p < 0.05$) elevation in GSH, SOD, and CAT enzymes.

Hypolipidemic Activity

Sophia and Manoharan (2007) studied the hypolipidemic activity of ethanolic extract from *F. racemosa* bark (100-500 mg/kg, b.w.) against alloxan-induced diabetic albino Wistar rats. The extract increased body and liver weight while decreased the kidney weight. The extract also reduced blood sugar level (80%) and restored the status of lipids and lipoproteins (60-70%) in treated rats.

Larvicidal Activity

Velayutham et al. (2013) studied the larvicidal effect of synthesized silver nanoparticles (AgNPs) utilizing aqueous bark extract of *F. racemosa* against *Culex quinquefasciatus* and *Culex gelidus*. The extract exhibited maximum efficacy with LC_{50} of 67.72 and 63.70 mg/l and synthesized AgNPs (12.00 and 11.21 mg/l) for *Cx. quinquefasciatus* and *Cx. gelidus*, respectively.

Rahuman et al. (2008) evaluated the larvicidal activity of gluanol acetate isolated from crude n-hexane, ethyl acetate, petroleum ether, acetone and methanol extracts from leaves and bark of *F. racemosa* against fourth-instar larvae of *Culex quinquefasciatus*, *Aedes aegypti* and *Anopheles stephensi*. All extracts showed moderate larvicidal effect, whereas acetone bark extract caused 100% larval mortality in 24 h at 1000 ppm. Further, gluanol acetate attained potent effect with LC_{50} values as 14.55 ppm (*A. aegypti*), 28.50 ppm (*An. Stephensi*) and, 41.42 ppm (*C. quinquefasciatus*), respectively.

Nephroprotective Activity

Khan and Sultana (2005) demonstrated the nephroprotective effect of petroleum ether, benzene, ethyl acetate, acetone, methanol, and double distilled water extracts (200 and 400 mg/kg, b.w.) of *F. racemosa* on potassium bromate ($KBrO_3$)-mediated renal oxidative stress and cell promotion response in albino Wistar rats. The extract dose-dependently inhibited enhancement of $KBrO_3$ -mediated activity of xanthine oxidase and renal microsomal lipid peroxidation, and reduction in the level of quinone reductase. Pre-treatment with extract showed reduction in the values of blood urea nitrogen, serum creatinine, γ -glutamyl transpeptidase and hydrogen peroxide by 71 to 96%, 133 to 241%, 44 to 74% and 80 to 109%, as well as recovered the renal glutathione, glutathione-S-transferase and glutathione reductase levels (15 to 21, 35 to 43 and, 16 to 29%) when compared with $KBrO_3$ -treated controls. The pre-treatment of extract at 200 mg/kg caused 224 and 102%, at

400 mg/kg dose caused 315 and 152% inhibition in elevation of ornithine decarboxylase activity and DNA synthesis.

Khan and Sultana (2004) reported the nephroprotective activity of methanolic extract (200 and 400 mg/kg, b.w.) of *F. racemosa* aerial parts against ferric nitrilotriacetate (Fe-NTA)-induced renal oxidative stress, hyperproliferative response and renal carcinogenesis in albino rats. Treatment with extract at tested doses showed a significant ($p < 0.001$) decrease in γ -glutamyl transpeptidase, lipid peroxidation, xanthine oxidase, H_2O_2 generation, blood urea nitrogen, serum creatinine, renal ODC, DNA synthesis and incidence of tumors, whereas renal glutathione content ($p < 0.01$), glutathione metabolizing enzymes ($p < 0.001$) and antioxidant enzymes were also recovered to significant level ($p < 0.001$). The extract showed a reduction in the enhancement of DNA synthesis by 136 to 164%.

Radioprotective Activity

Veerapur et al. (2009) assessed the radioprotective potential of ethanol extract (2-150 mg/ml) of bark of *F. racemosa* against radiation-induced micronuclei (MN) yields in irradiated Chinese hamster lung fibroblast (V79) cell lines. The percentage of MNBNC (micronucleated binucleate cells) in V79 cells was significantly ($P < 0.05$ and $P < 0.001$) lower after 1 hour of treatment with varying concentrations of FRE (2, 5, 10, 20, 50, 75, 100, 125, and 150 μ g/ml) than in the radiation alone group.

Wound Healing Activity

Bopage et al. (2018) evaluated the wound healing activity of lupeol, β -sitosterol and lupeol acetate isolated from dichloromethane, ethyl acetate, methanol, and n-hexane extracts of *F. racemosa* stem bark using scratch assay (SWA) on Baby Hamster Kidney (BHK 21) and Madin-Darby Canine Kidney (MDCK) cell lines. Both n-hexane and dichloromethane extract significantly ($p \leq 0.05$) enhanced wound healing and, percentage of wound closure was increased at 24 hr. Further, both lupeol and β -sitosterol exhibited cell migration enhancement in both cell lines at 24 h as compared to asiaticoside used as positive control. Although, lupeol acetate also increased cell migration enhancement activity with time and, percentage healing of 74% in BHK cell line and, 72% in MDCK cell line at 48 h.

Murti and Kumar (2012) performed the wound healing activity of aqueous and ethanolic extracts of *F. racemosa* roots using incision and excision wounds in albino Wistar rats. The breaking strength of incision wounds (497.20 and 394.70) was increased by both extracts as compared to povidone iodine used as standard drug with breaking strength of 352. The wound contracting ability of both extracts was significantly greater than control. Also, the ethanolic extract ointment exhibit a significant wound contraction from fourth day onwards and, achieved 100% contraction with wound closure time of 14.17 days.

Clinical Study

Clinical studies often vary in terms of methodology, dosages, and patient populations, making it essential to consider the overall body of evidence when assessing the plant's therapeutic potential. Several clinical studies were conducted to identify the effectiveness of *F. racemosa* extracts and bioactive constituents. In addition, *F. racemosa* have explored various potential health benefits and traditional uses. Ahmed et al. (2011) performed a free-living, double-blinded, randomized, placebo-controlled study including type 2 diabetic individuals (18 men and 12 women) aged between 35 and 50 years who took the aqueous extract of *F. racemosa* bark (FRAE; 1.2 g / day (400 mg × 3 capsules).

The extract treated group showed a significant reduction ($p < 0.05$) in both fasting blood glucose (15%) and postprandial blood glucose (22%) compared with control group after 1-month supplementation period. Whereas significant increase ($p < 0.05$) in insulin levels in extract treated group was observed. However, extract did not show any changes in total cholesterol, and triglycerides levels in treated extract group. More clinical and pathological studies should be conducted to investigate the active potentials of bioactive compounds present in this plant which can help in proving it to be a promising source as a nutraceutical as well as pharmaceutical.

Toxicological Profile

F. racemosa, is a medicinal plant that has been used in traditional systems of medicine, such as Ayurveda and traditional Chinese medicine, for various purposes. While it possesses several potential therapeutic benefits, it's important to consider the toxicological profile of *F. racemosa* as well. Jaykaran et al. (2009) performed the acute toxicity of aqueous extract of *F. racemosa* bark in albino mice. Some physiological changes were also observed in the liver and kidney. The extract was safe up to the highest dose of 1000 mg, but it produced abnormality in the liver and kidney. The fasting blood sugar level pointed toward hypoglycemia. Panwar et al. (2010) performed acute and subacute

toxicity of aqueous extract (30 mg/100 gm, b.w.) of *F. racemosa* bark in albino mice and albino Wistar rats. Liver damage was seen in the sub-acute toxicity study and reversible hepatotoxicity was also observed during the experiment. The extract did not show any signs of renal damage during the histopathological studies, but the creatinine and urea levels had increased dramatically. Solanki and Bhavsar (2014) evaluated the toxicity of aqueous extract of *F. racemosa* in albino Wistar rats. The extract did not show any mortality and signs of neurological and behavioral changes were noticed within 72 h as well as no significant change in body weight, while significant changes were observed of liver parameters.

Further, no significant change was found in creatinine and total protein level, while hematological parameters. Histopathology

revealed no structural changes in the heart, kidney, liver, and nerve tissues.

Summary and Future Outlook

F. racemosa is a tree species with a long history of medicinal use in traditional medicine systems, especially in South Asia. Its pharmacology encompasses a wide range of potential health benefits, many of which have been explored through scientific research. In conclusion, *F. racemosa* has a rich pharmacological profile with various potential health benefits, ranging from anti-inflammatory and antioxidant effects to anti-microbial and hepatoprotective properties. While there is substantial evidence supporting many of its pharmacological effects, it's important to note that further research is needed to fully understand the mechanism of action, identify specific active

compounds, and validate its efficacy in clinical settings. Additionally, safety considerations and potential interactions with medications need to be thoroughly investigated. Its outlook involves in-depth research to unlock its full potential, identify active compounds, conduct clinical trials, explore new therapeutic applications, and ensure its safe and effective use in various medical and pharmaceutical contexts. A multidisciplinary approach, combining traditional knowledge with modern scientific methods, will contribute to a better understanding of this versatile plant's medicinal properties and its role in improving human health.

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