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REVIEW ARTICLE

Indigenous medicinal flora of Northeast Indian Himalayan range as promising remedies for emerging and re-emerging diseases

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Abstract

To meet the needs for health and wellness, people have long turned to home cures, traditional healers and traditional medical knowledge. Several modern pharmaceutical products such as Aspirin, Artemisinin are derived from natural sources and traditional wisdom. The scientists behind these drugs clearly depended on traditional knowledge to make their remarkable discoveries. The Northeast states of India comprising of eight states distinguish themselves for their rich biodiversity, diverse culture and ethnic groups and their diverse medicinal flora constitutes the most distinctive feature. The traditional wisdom and practices of these tribes have helped identify therapeutic plants that are now used or studied in present-day medical treatments. Despite facing challenges in documenting and preserving this folk wisdom, exploration through survey and scientific studies of these valuable resources can enhance research, conserve rare species and even promote entrepreneurship among local youths. These indigenous plants could be more than just traditional remedies. They could assist in the development of novel medications to combat emerging and re-emerging diseases such as COVID-19, HIV, cancer, dengue, yellow fever and others. This paper presents a comprehensive examination regarding the uses and potential of numerous indigenous medicinal plants utilized in the Northeast regions, which have been historically used to address a range of ailments. Further investigations into these plants may pave the way for breakthrough research.

Keywords: ethnobotany; good health; Himalayas; indigenous; medicinal plants; Northeast India

Introduction

Historically, humans have depended on nature for vital necessities, including food production, shelter, clothing, transportation, fertilisers, flavours, fragrances and importantly, medicine (1). For centuries, traditional practices have relied on medicinal plants to address a range of viral infections and facilitate healing from injuries. Plants are vital for the ongoing existence of tribal and ethnic societies and are major suppliers of medicinal medications (2). Nearly 80 % of the world's population relies on herbal remedies for their medical needs, with millions of people primarily residing in rural parts of poor nations (3,4). Herbal medicine is in high demand around the world and continues to rise (5). It is predicted that the Indian market for ayurvedic medicines is growing at a rate of 20 % per year. It was reported that the medicinal plants sourced from Chinese province (Yunnan) has increased by tenfold in the past ten years and it might be increased by more by this 2025 (2). The pharmaceutical industry is increasingly drawn to the potential of natural products found in medicinal plants due to their lower side effects, effectiveness and widespread availability. Medicinal plants play a crucial role as a rich source for isolating and identifying bioactive phytoconstituents, including terpenoids, coumarins, alkaloids, flavonoids, saponins and more (6).

Various emerging and re-emerging viral diseases such as Zika virus, COVID-19, Ebola, STIs (Sexually Transmitted Infections), meningitis, dengue, yellow fever, etc. pose significant health threats globally. While various strategies such as vaccines, interferon therapies and small-molecule drugs have been proposed to control or prevent these infections, their development is expected to take months or even years. Additionally, many existing antiviral treatments face challenges such as viral resistance, adverse side effects and the risk of viral resurgence or dormancy. Pharmaceutical companies are now concentrating on developing alternative antiviral medications by exploring phytochemical extracts, herbs as potential sources for identifying useful compounds. Natural products such as Essential Oils (EOs),

herbal remedies, distilled botanicals and spices offer a wealth of potential for discovering and producing new antiviral treatments (7). The Northeast regions of India, situated between the Himalayas to the North and the Bay of Bengal to the South, constitute a unique narrow corridor linking the Indian subcontinent to East Asia and Southeast Asia (8). This region consists of eight states: Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura, each inhabited by diverse ethnic populations that possess significant traditional knowledge and traditions inherited through generations (9). For anthropologists and ethnobotanists, the region serves as an invaluable resource for vegetation. Numerous research institutes, universities and government organizations have studied how the indigenous tribes and communities in these areas use plant resources during the past four to five decades (10). The varied climate, soil types and elevation in this region create a rich tapestry of ecological environments. This area serves as a habitat for numerous wild relatives of cultivated plants, such as orchids, bananas, bamboos, citrus fruits, ginger-turmeric, palms and others (11). This area serves as a pivotal junction connecting the Indian, Indo-Malayan and Indo-Chinese biogeographic regions, where the Himalayan mountains meet Peninsular India. In the past, it was associated with the northward movement of the Deccan Peninsula (12). Due to various factors such as forest destruction, clearing land for agriculture, urbanisation, mining operations, etc., there is a significant genetic loss or threat of extinction for several therapeutic plants today, although specific information is unavailable. Appropriate conservation efforts for medicinal plant species that are on the verge of extinction have not been taken up or largely unsuccessful, due to lack of information and materials in the gene banks. Furthermore, there has been an excessive focus on the possibility of finding new miracle medications and insufficient attention paid to numerous issues associated with local populations using traditional medicines (13). Conservation seeks to foster sustainable development by safeguarding the variety of genes and species globally, while also working to prevent the degradation of vital habitats and ecosystems through careful management and utilization of biological resources. Activities including gathering, propagation, characterization, assessment, indexing, storage and distribution are generally involved in the conservation process. Plant genetic resource conservation has long been understood as a crucial component of biodiversity conservation and is employed through two different approaches *in-situ* and *ex-situ* (14). In total, around 470 relevant publications have been recorded, including 402 research articles, 41 chapters in edited volumes, 20 standalone books and 7 papers presented at various seminars and workshops. Among the eight states, Assam stands out with 156 entries, followed by Manipur with 53, Arunachal Pradesh with 49, Meghalaya with 47, Sikkim with 42, Nagaland with 32, Mizoram with 25 and Tripura with 22. Furthermore, there are 44 publications that address various subjects related to Northeast India. Within the various work categories, ethnomedicine emerges as the most prominent, boasting a total of 243 works. It is closely followed by ethnobotany, which has 89 works and wild food, with 84. The categories of religious and supernatural beliefs and traditional conservation practices show lesser representation, with 11 and 10 works respectively. Ethnoveterinary practices account for 9 works, while local drinks and herbal dyes each have 6. Pest management is represented by 5 works and seasons indicator plants have 3. The categories of drugs, family planning and birth control and traditional weaving implements each have a single work to their name (10). Although the Northeast states boast impressive biodiversity, there remains a considerable gap in the documentation of these medicinal plants. Therefore, this review addresses the existing gap by providing a comprehensive compilation of information on plants native to the region and provides an insight into the various medicinal plants utilized by the various indigenous communities as traditional medicine, emphasizing their potential for healing possibilities of emerging and re-emerging diseases, thus providing a significant resource for researchers, healthcare professionals and policymakers in search of innovative remedies derived from nature.

Methodology

A comprehensive and methodical examination of the existing literature was conducted, focusing on key subjects such as distribution, traditional and contemporary applications, phytochemistry and the biological activities of various medicinal plant species. This information was meticulously gathered from a range of databases, including PubMed, Scopus, Web of Science, Google Scholar, JSTOR, CAB Abstracts, Medline, Embase, INMEDPLAN, NATTS, as well as from websites like www.jstor.org, www.sciencedirect.com, www.eflora.org, www.pfaf.org and www.worldfloraonline.org. The examined literature included a variety of abstracts, full-text articles, books, PhD theses and blogs. A total of 94 highly pertinent references were meticulously selected for an in-depth analysis and were considered for the development of this manuscript.

Geographical location, climate and terrain of Northeast India

The Northeast region of India, often referred to as the seven sisters and one brother, includes the states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura (Fig. 1). The region spans a geographical area of 2.62 lakhs, representing around 8 % of India's total land area. It stretches between latitudes 21°34′ N to 29°50′ N and longitudes 87°32′ E to 97°52′ E. Arunachal Pradesh is notable for being the largest state, covering an area of 83743 km^2, whereas Sikkim is recognized as the smallest, with a geographical extent of 7098 sq. km. Located at the eastern foothills of the Himalayas, Northeast India shares its borders with Bangladesh, Bhutan, China, Nepal and Myanmar (10).

Northeast India presents a diverse climatic landscape, predominantly defined by a humid subtropical climate that includes hot and humid summers, vigorous monsoon seasons and mild winters (15). Northeast India exhibits a diverse climatic landscape that can be categorized into two main zones. The Alpine or Montane zone, which includes Arunachal Pradesh and Sikkim, experiences cold, snowy winters alongside mild summers. In contrast, the humid subtropical zone encompasses the remaining states of the region, marked by hot and humid summers, intense monsoons and mild to medium winters (12). The Northeast region of India showcases a rich variety of landforms, including plains, plateaus, mountains and valleys. This region can be divided into three primary categories: the Meghalaya Plateau, the Northeastern hills and basin and the Brahmaputra Valley. The states in this region experience varying levels of rainfall, with an average minimum of 1650 mm and a

Fig. 1. Seven sisters and one brother state of Northeast India.

maximum of 6320 mm. Most of the annual rainfall, approximately two-thirds, occurs during the monsoon months from April to September. The temperatures in the region range from below 0 °C to as high as 38 °C (16).

Diversity of flora and fauna in Northeast India

Northeast India has garnered attention due to its remarkable biodiversity. The abundance of avifauna in the region mirrors the variety of habitats found across different altitudes (17). More than half of India's flowering plant species, totalling over 8000 out of 15000, are present in the Northeast region. This includes 40 gymnosperm species, 500 pteridophytes, 825 orchids, 80 rhododendrons, 60 bamboo species and 25 types of canes. The region is home to a diverse array of wildlife, with 3624 insect species, 50 molluscs, 236 fishes, 64 amphibians, 137 reptiles, 850 bird species and 160 mammalian species identified so far (18). However, there are still numerous species awaiting description. Among the primates in India, comprising 15 known species across three families, nine are found in the Northeast. Additionally, the region supports four out of the six largest cat species globally, with the Clouded Leopard's Indian population primarily concentrated in the Northeast. The Northeast boasts 51 distinct types of forests, including tropical moist deciduous, tropical semi-evergreen, tropical wet evergreen, subtropical, temperate and alpine forests (19). Out of 9 important vegetation types of India, six are found in the north-east regions. The region is indeed rich in biodiversity, especially when it comes to flowering plants. Arunachal Pradesh stands out with over ±5000 species, making it one of the most botanically diverse places in the country. Sikkim follows closely with around ±4500 species, while Meghalaya boasts approximately ±3500 species. Assam is not far behind with ±3010 species, followed by Manipur with ±2500, Nagaland with ±2250, Mizoram with ±2200 and Tripura with ±1600 species. Additionally, some plants species belonging to the families Napanthaceae, Llilliciaceae and Clethraceae found in this region are unique in the world (17). This underscores the region's lushness and emphasizes its status as a haven for diverse flora and fauna.

Diverse ethnic groups and indigenous wisdom of Northeast India

In addition to its unparalleled biodiversity, this region stands as a model example of 'unity in diversity'. Several indigenous, tribal ethnic groups inhabit this area, each characterized by physical and cultural distinctions (20). The Northeast states are home to over 200 distinct tribes, each with its own unique dialects, customs, beliefs, heritage and socio-religious traditions (21). The ethnic communities residing in this region have been instrumental in generating, refining and passing on traditional knowledge from one generation to the next. This knowledge, rooted in their needs, instincts, observations, trial and error and extensive experience, forms an integral part of their cultural identities (22). The utilization and understanding of local plants vary among these ethnic groups, each having their own unique approach. Notably, the use of medicinal plants holds significant importance in the healthcare practices of tribal communities (10). This underscores the crucial role traditional knowledge plays in ensuring the well-being of these communities, providing insights into sustainable practices and fostering a harmonious relationship between the people and their environment. Table 1 presents a compilation of diverse tribes found in the Northeast states.

Exploring novel pharmaceuticals through ethnomedicine

Plants have been essential to traditional medicinal systems, with a historical usage extending over millennia in nations such as China and India (24,25). The comprehensive documentation of plants in traditional medicine across several civilizations underscores their lasting importance. The World Health Organization estimates that 80 % of the global population primarily depends on traditional medicine systems. In developed nations where 20 % of the population live, botanical products remain integral to healthcare systems and the use of alternative herbal products has increased in recent decades. Of the 119 botanical drugs studied, 74 % were identified through chemical investigations focused on isolating active compounds from plants utilized in traditional medicine (26). Indigenous herbs enhance contemporary medicine in four essential manners. Firstly, tropical plants are directly employed as sources of medicinal compounds. Secondly, these plants function as precursors for the synthesis of semi-synthetic chemicals. Thirdly, tropical flora offers chemicals that can act as models for the development of novel synthetic molecules. Cocaine derived from Coca plant, *Erythroxylum coca*, has prompted the development

Table 1. Various tribal communities and ethnic groups of the eight Northeast Indian states (10,21,23)

State	Area (sq.km)	Tribal Communities
Assam	78438	Baiate, Barmans in Cachar, Bhoi, Borokachari, Boro, Changsan, Chakma, Chongloi, Deori, Dimasa, Doungel, Garo, Gamalhou, Gangte, Guite, Haolai, Hanpit, Hao Kip, Hengna, Hmar, Hongsungh, Hrangkhwal, Jaintia, Kachari, Khasi, Khothalong, Kipgen, Kuki, Lakher, Lengthang, Lhangum, Lhonyem, Lhoujem, Lhouvum, Lyngngam, Man (Tai speaking), Mangje, Mech, Mikir, Misao, Miri, Pawi, Pnar, Rabha, Raokhol, Riaong, Sairhem, Selnam, Singsom, Singson, Sithou, Sonwal, Sukto, Syntheng, Synteng, Tai Mizo (Lushai), Thado, Thangngeu, Tongbe, UibushVaiphel, War
Arunachal Pradesh	83743	Aka, Adi, Angami, Ao, Aptani, Bangani, Bugun, Chugppa, Galo, Hill Miri, Hrusso, Idu Mishmi, Khampti, Khamba, Khowa, Koro, Lisu (Yobin), Memba, Meyor (Zakhring), Miji, Mishmi, Mishing Miri, Monpa, Mongpa, Naga, Nocte, Nyishi, Sajolang, Sartang, Sherdukpen, Singpho, Sulung, Tagin, Tai Khamti, Tangsa, Wancho and Yobin
Meghalaya	22429	Synteng, War, Lakher, Rabha, Mizo (Lushai), Kuki, Karbi (Mikir), Boro, Khasi, Chakma, Pnar, Garo, Man (Tai speaking), Hmar, Jaintia, Koch, Lyngngam, Naga, Pawi, Bhoi, Dimasa, Hajong
Mizoram	21081	Any Kuki (Baiate, Changsan, Chongloi, Doungel, Gamathou, Gangte, Guite, Hanneu, Hao Kip Hanpit, Lhonyem, Lhocwun, Lupheng, Mangje, Misao), Any Mizo (Lushai tribe), Chakma, Dimasa Kachari, Garo, Hajong, Hmar, Jaintia, Karbi, Khasi, Khawathlang, Khothalong, Khawchung, Khelma, Kholhou, Kipgen, Kuki, Lengthang, Lekher, Lhangum, Lhoujem, Lhouvum, Man (Tai speaking), Misao, Pawi, Raokhol, Riang, Sairhem, Selnam, Singsom, Singson, Sitlhou, Sukto, Synteng, Thado, Thangngeu, Tongbe, Uibush, Vaiphei and War
Manipur	22327	Aimol, Anal, Angami, Any Mizo (Lushai) , Chethe, Chiru, Gangte, Hmar, Kabui, Kacha Naga, Koirao, Koireng, Kom, Lamgang, Mao, Maring, Maram, Monsang, Moyon, Paite, Purum, Ralte, Sema, Simte, Suhte, Tangkhul, Thadou, Vaiphui, Zou, Meitei, Naga, Kuki
Nagaland	16579	Adi, Aka, Ao, Chakhesang, Chang, Chiru, Dimasa, Galong, Garo, Jaintia, Khasi, Khiemnungan, Khowa, Konyak, Kuki, Lotha, Mizo, Makwari, Mikir (Karbi), Momb, Naga (Any tribe: Ao, Angami, Chakhesang, Chang, Chiru, Khiemnungan, Konyak, Lotha, Makwari, Phom, Rengma, Sangtam, Sema, Tikhir, Yimchungree, Zeliang), Ngami, Phom, Pochury, Rengma, Sangtam, Sema, Sumi, Syntheng, Yimchungru, Zeliang
Tripura	10491	Bhil, Bhutia, Chaimal, Chakma, Garo, Halam, Jamatia, Kaur, Khasia, Kuki, Lepcha, Lushai Mag, Munda, Noatia, Orang, Reang, Santhal, Tripuri, Uchai
Sikkim	7096	Bhutias , Lepchas, Limboos, Nepalese and Tibetans

of several local anaesthetics, including procaine. Finally, plants serve as significant taxonomic indicators, facilitating the identification of novel chemicals (27).

Medicinal plants of Northeast regions and their traditional therapeutic uses

For ages, the people living in the Northeast regions leaned on the rich flora to treat a variety of illnesses. The traditional medical systems, which have their roots in indigenous medicine and ayurveda, are typically based on a profound knowledge of the beneficial properties of local flora. The Northeast states are home to a distinctive collection of therapeutic plants, each of which adds to the local medical customs. The discussion below provides insights into various states and the medicinal plants commonly utilized by the diverse communities in each region.

Meghalaya

Meghalaya, which is often referred to as the Scotland of the East, is a place of unending joy and tranquillity encased in breath-taking beauty. Forests encompass 9496 sq. km or 42.34 % of Meghalaya's overall land. One of Asia's richest botanical environments is thought to be the subtropical woods of Meghalaya. A wide range of floral and faunal species is supported by these forests, which get copious amounts of rainfall. There are over 3128 species of flowering plants in the state and 40 % of them are indigenous to the state. 850 species of plants with medicinal properties are found in Meghalaya, 377 of which are used for primary medical care by a large portion of the population. The native people have long used plants as remedies and have extensive knowledge regarding those (28). Table 2 presents a compilation of several plants employed by local communities from Meghalaya for medicinal purposes.

Manipur

In the heart of the state lies the Imphal valley, home to the Meitei and Meitei Pangal communities, while the surrounding hilly expanses are inhabited by 30 distinct tribes, including the Kuki and Naga tribes. Manipur is distinguished by its diversified topography, encompassing both the Himalaya and Indo-Burma

Table 2. Medicinal plants indigenous to Meghalaya and their therapeutic applications (29,30, 31)

Scientific name	Local name	Family	Traditional medicinal uses
Achyranthes aspera L.	Sohbyrthit	Amaranthaceae	Wounds and injuries are treated using a paste produced from the leaf buds. To treat dental issues, the roots are chewed and utilised as brushes
Crassocephalum crepidioides (Bentham) S. Moore	Sla-aeroplane	Asteraceae	The leaves of plants are used as pig feed and as fish poison
Elephantopus scaber L.	Kymbat-skur, Sniang	Asteraceae	For the treatment of diarrhoea and urinary tract infections, the leaves and root extract are utilized. The leaves combined with boiling rice are supposedly used as a remedy for harmful bug bites
Houttuynia cordata Thunb.	Jamyrdoh	Saururaceae	It is used to treat diarrhoea, dysentery, flatulence, skin conditions, gonorrhoea, measles, sinusitis and lowering blood glucose level
Eupatorium odoratum L. [syn. *Chromolaena odorata* (L.) R.M. King and H.E. Robins]	Krah-lynroh	Asteraceae	The extract of leaves is used to cure diarrhoea and to halt bleeding
Galinsoga parviflora (Cav.)	Tiew-lien	Asteraceae	To halt bleeds, crushed foliage along with lime is applied. A treatment to dangerous bug stings and snake bites is a paste made of roots and foliage
Siegesbeckia orientalis L.	Soh-barthudip	Asteraceae	For wounds and injuries, crushed foliage is used
Sonchus asper L..	Jangew	Asteraceae	The tender leaves are consumed as vegetable
Spilanthes acmella (L.)	Byshit-iong	Asteraceae	Dried leaf powder is supposed to work well for mouth blisters and toothaches
Lantana camara Linn.	Lantana	Verbenaceae	Fish can become intoxicated or killed by pulverised seeds
Zanthoxylum acanthopodium DC.	Jaiur	Rutaceae	Berries assist with gastrointestinal issues; bark is utilized for alleviating dental pain; leaves and fruits are employed in the management of diabetes

biodiversity hotspots. Despite constituting merely 8 % of India's total geographical area, this region contributes to a staggering 50 % of the country's biodiversity. The region's diverse flora boasts a high degree of endemism, encompassing valuable plants with medicinal properties. Throughout history, these various plant species have been integral to the ethnic therapeutic practices of Manipur's diverse communities. Herbal remedies, derived from over 1200 reported plant species with medicinal importance, play a crucial role in disease treatment, prevention and overall immune enhancement (32). Table 3 presents a compilation of several plants employed by local communities in Manipur for medicinal purposes.

Mizoram

Tropical evergreen and semi-evergreen forests make up the bulk of Mizoram's vegetation in the lower hills, while higher hills see a shift to subtropical and montane subtropical vegetation. Notably, Mizoram faces a significant challenge in healthcare resources, with a notably low number of doctors and medical staff in comparison to its total population, indicated by a doctor-to-population ratio of 1:3415 in 1994 (35). Adding to the healthcare challenges is Mizoram's challenging topography, contributing to an underdeveloped communication system in the state. This geographical factor limits access to modern medical treatments, particularly for residents in rural areas, prompting a reliance on natural remedies sourced from the rich biodiversity of the region (36). Table 4 presents a compilation of several plants employed by local communities in Mizoram for medicinal purposes.

Arunachal Pradesh

Arunachal Pradesh stands out as one of the largest states in Northeast and it is characterized by a diverse population comprising 28 major tribes. Each of these ethnic groups

Table 3. Medicinal plants indigenous to Manipur and their therapeutic applications (33,34)

Scientific name	Local name	Family	Traditional medicinal uses
Acorus calamus Linn.	Oak-hidak (Sweet flag)	Araceae	The treatment of coughs, fever and itching often involves the utilization of leaves, roots and rhizomes
Ardisia crenata Sims	Uthum	Primulaceae	Leaves are employed in the treatment of both coughs and diarrhoea
Cannabis sativa L.	Ganja	Cannabaceae	Leaves are utilized in the treatment of piles and dysentery
Centella asiatica (L.)	Peruk	Apiaceae	The entire leaf or plant is employed in addressing high blood pressure, typhoid, nasal bleeding and sore throat
Helianthus annus L.	Sunflower/ Numit lei	Asteraceae	Seeds and leaves are utilized in the treatment of muscular pain, cold, cough and bronchitis
Houttuynia cordata Thunb.	Toningkhok	Saururaceae	Leaves and roots are used in traditional medicine for conditions like dysentery, stomach issues, skin and eye irritations and muscular pains
Pinus kesiya Royle ex. Gordon	Baguio pine andUchan	Pinaceae	Wood and leaves are employed in addressing issues such as cough and headaches
Plantago erosa (Wall.) Z. Yu Li	Yempat	Plantaginaceae	Leaves, seeds and roots are used to alleviate conditions like stomach pain, swelling, jaundice and boils
Cymbopogan flexuosus (Nees ex Steud.) Will.Watson	Houna	Poaceae	Leaves are used to treat throat problem, back pain as well used as a hair care lotion
Zanthoxylum acanthopodium DC.	Mukthrubi	Rutaceae	Fruits and leaves are utilized in the treatment chronic fever, indigestion, cough and bronchitis
Zanthoxylum armatum DC.	Tekhao-yaikhoo	Rutaceae	The rhizome is employed in addressing various health issues such as cancer, joint pain, stomach ache, morning sickness and vomiting

Table 4. Medicinal plants indigenous to Mizoram and their therapeutic applications (35,37)

Scientific name	Local name	Family	Traditional medicinal uses
Abelmoschus moschatus Medik.	Uichhuhlo (Musk mallow)	Malvaceae	The treatment for syphilis involves the administration of boiled roots and leaves. Additionally, crushed roots are externally applied to wounds and ulcers to facilitate the extraction of pus. For alleviating throat pain, seeds are ground into a powder, which is then consumed with water twice daily
Blumea laciniata (Wall. ex Roxb.) DC.	Khuanglawr	Asteraceae	The paste extracted from the root is employed as a remedy against snake bites. Concurrently, the affected area is externally applied with juice obtained by crushing the leaves
Cammelia sinensis (L.) Kuntze	Thingpui	Theaceae	Boiling tea leaves is a practice utilized for its astringent, stimulant and diuretic properties
Centella asiatica (L.)	Lambak/ Hnahbial	Apiaceae	Known for its memory-enhancing properties, this remedy involves boiling the leaves and consuming the infused water. It is employed as a treatment for asthma and eye problems, while also being utilized in managing hypertension
Desmodium triflorum (L.) DC.	Bawngkek-hloLalram	Fabaceae	Decoction from boiled leaves serves as a treatment for renal disorders and urinary complications. Additionally, the juice extracted from fresh leaves is applied topically on wounds
Eucalyptus globules Labill.	Eucalyptus	Myrtaceae	An infusion of the leaves is ingested to address pneumonia, while charcoal is either ground into a powder or made into a paste and consumed as a remedy for stomach ulcers. Furthermore, a decoction of the leaves is employed in the management of diabetes
Ficus religosa L.	Hmawnghnahzum	Moraceae	Utilized for its astringent, antigonorrhoeic, antidysenteric, febrifuge and scabies properties, the plant also serves as a remedy for piles. The leaves and young shoots are applied as a purgative and for the treatment of skin diseases
Garcinia cowa Roxb. ex Choisy	Chengkek	Clusiaceae	The bark, known for its antidiarrheal and antileprotic properties, is also employed in the treatment of ulcers
Lantana camara Linn.	Hlingpangpar	Verbenaceae	Known for its antirheumatic and antimalarial properties, the substance is also effective in treating tetanus, serving as a diaphoretic, carminative and antispasmodic
Zanthoxylum armatum DC.	Arhrikreh	Rutaceae	The leaves are employed to repel fouls and lice, while the fruit acts as an appetizer and is utilized for its anticephalgic, antiasthmatic, antihelminthic properties, as well as in the treatment of leucoderma, eye and ear diseases and piles. Additionally, the flower serves as an antidote for snake bites

possesses distinctive dialects, customs, traditional beliefs and cultural identities, contributing significantly to the region's cultural richness. Recognized as a focal point for medicinal plants, Arunachal Pradesh has rightfully earned the designation of a 'paradise for ethno-botanists and anthropologists.' Boasting an impressive array of approximately 500 species of vital medicinal plants, the state sees extensive use of these resources by its diverse ethnic communities. These plants not only play a pivotal role in traditional healing practices but also present significant opportunities for research in the realm of herbal medicine. The abundance of medicinal flora in Arunachal Pradesh underscores the ecological importance of the state and its substantial contribution to the traditional knowledge of herbal remedies (38). Table 5 presents a compilation of several plants employed by local communities in Arunachal for medicinal purposes.

Tripura

Tripura spans an area of 10491.69 km^2 and is home to a wide range of distinct ethnic groups, including Tripuri, Bengali, Debbarma, Reang, Naotia, Chakma, Bhil, Bhutia, Chaimal, Garo, Halam, Khasia, Kuki, Lepcha, Mog, Munda, Orang, Santhal, Uchoi, Koloi, along with numerous other smaller communities. There is a wealth of traditional expertise regarding medicinal plants within each community of the state and each community has its own way of passing this knowledge down through the generations (41). This information covers the medicinal uses of both generic over-the-counter medicines and the more specialised treatments developed by individual traditional healers. Kaviraja refers to local ayurvedic practitioners, whereas Ojha describes individuals who practise community-specific folk medicine. Local groups in Tripura utilize a variety of plants for medical purposes, as presented in Table 6.

Nagaland

Nagaland, a small state in Northeast India located in the Indo-Burma biodiversity hotspot, showcases a rich variety of flora and fauna, complemented by a spectrum of climates that range from warm and subtropical in the plains to moderate and sub-montane in the mid-slopes and cool and temperate in the high hills. The Naga tribe in Nagaland consists of a diverse array of indigenous groups, such as the Angami, Ao, Chakhesang, Chang, Khiamniungan, Konyak, Lotha, Phom, Pochury, Rengma, Sangtam, Sumi, Yimchungru and Zeliang. For centuries, the Naga tribe has depended on medicinal plants to treat a range of illnesses with their traditional knowledge of these plants passed down through generations (43). Table 7 presents a collection of various plants utilized by local communities in Nagaland for their

Table 5. Medicinal plants indigenous to Arunachal Pradesh and their therapeutic applications (39,40)

Scientific name	Local names	Family	Traditional medicinal uses
Ageratum conyzoides L.	Paas pai	Asteraceae	Paste made from leaves is employed as a blood coagulant
Begonia roxburghii (Miq.) A. DC.	Baprai	Begoniaceae	Leaves and raw stems are utilized for alleviating stomach ache
Cassia alata (Linn.) [syn. *Senna alata* (L.) Roxb.]	Nyoro talleh	Leguminosae	Paste prepared from leaves is used for removal of ringworm
Drymaria cordata (L.) Wild. Ex Schult.	Pipi	Caryophyllaceae	Boiled or raw leaves are employed in the treatment of fever and cough
Eupatorium odoratum L. [syn. *Chromolaena odorata* (L.) R.M. King and H.E. Robins]	Wo pohing	Asteraceae	Paste made from leaves is utilized as a blood coagulant
Mimosa pudica L.	Reseh	Fabaceae	Root decoction is employed for alleviating toothache
Ocimum sanctum Linn.	Tulsi	Lamiaceae	Leaves decoction is used for treating stomach ache and loose motion
Hibiscus rosa sinensis L.	Jovaphool	Malvaceae	Paste or boiled leaves are applied for the treatment of cough, fever and for hair treatment
Piper mullesua Buch.-Ham. ex D.Don.	Namar	Piperaceae	Fruit decoction is employed for the treatment of vein problems
Zanthoxylum rhetsa (Roxb.) DC.	Ongear	Rutaceae	Stem is utilized for conditions like gastritis and diabetes and fruits as a spice

Table 6. Medicinal plants indigenous to Tripura and their therapeutic applications (41,42)

Scientific name	Local name	Family	Traditional medicinal uses
Aegle marmelos (L.) A. Lyons	Bael	Rutaceae	Fruit is used to address indigestion (prepared as a decoction and consumed as a drink) and weak heart (prepared as a decoction and consumed as a drink).
Azadirachta indica A. Juss.	Neem	Meliaceae	Leaves are employed to alleviate indigestion, fever and tuberculosis (prepared as a decoction and consumed as a drink)
Calotropis gigantean (L.)	Akanda	Asclepiadaceae	Leaves are used for addressing urinary troubles, prepared as a decoction and consumed as a drink
Cinnamomum verum J.S. Presl (Cannellier)	Dalchini	Lauraceae	For asthma, the bark is crushed and rubbed, suggesting a traditional method of preparation or application
Cocos nucifera (L.)	Narikul	Arecaceae	For teeth infection, the leaves are crushed and rubbed, indicating a traditional method of preparation or application
Datura stramonium (L.)	Dhutra	Solanaceae	Knee pain leaf crushed rubbed
Euphorbia neriifolia L.	Shairapul/ Shibgach	Euphorbiaceae	For pneumonia, the whole plant is prepared as a decoction and consumed as a drink, reflecting a traditional approach to addressing this health condition
Jasminum sambac (L.) Aiton	Beli	Oleaceae	For bone fractures, the leaves are crushed and rubbed, indicating a traditional method of application for potential relief or treatment
Moringa oleifera L.	Sajna	Moringaceae	For jaundice, the bark is crushed into pellets, suggesting a traditional method of preparation for potential use in managing or addressing jaundice
Citrus maxima (Burm.) Merr.	Jambura	Rutaceae	For indigestion, the fruit is crushed and consumed as a drink, indicating a traditional method used to address digestive issues

Table 7. Medicinal plants indigenous to Nagaland and their therapeutic applications (44,43)

Scientific name	Local name	Family	Traditional medicinal uses
Adhatoda vasica L. (Nees.)	Sangtamtu	Acanthaceae	Warming 8-10 leaves over a fire and locally applying them for treatment of lower back pain, joints and sprains
Allium ascalonicum L.	Rupchi	Amaryllidaceae	Fresh leaves are either macerated or pulverised for application on wounds. 5 mL of leaves juice is consumed orally as an anthelmintic
Aloe vera Linn.	Alonaro	Asphodelaceae	Cooling effect is achieved by crushing fresh leaves and applying it to burnt area
Capsicum annum L.	Mersu	Solanaceae	Crushed fruits are used as both an antipruritic (relieving itching) and a counter irritant
Centella asiatica (L.)	Longshikok	Apiaceae	3-4 teaspoonfuls of leaf juice mixed with an equal amount of milk for treatment of diarrhoea
Passiflora edulis f. edulis (Sims)	Antsulashi	Passifloracea	8-10 fresh leaves are boiled with water for acute dysentery and hypertension treatment. Consumption of fruits provide relief from constipation
Psidium guajava L.	Motiramtu	Myrtaceae	8-10 fresh leaves and 10 g of bark are boiled in 100 mL water for treating severe diarrhoea
Spondius mangifera (L.f.) Kurz	Mezunglashi	Anacardiaceae	Fresh leaves are crushed and applied topically to treat foot and toe infections. Also, crushed bark serves as a cooling agent when applied to burns
Urtica urens L.	Jaklemtsu	Urticaceae	Consumption of decoction from boiled 10-12 leaves with glass of water helps to alleviate constipation, stomach disorders and is used as a diuretic. Roots are crushed and applied as a layer for relief from edema
Zingiber officinale Roscoe	Sung sung	Zingiberaceae	Small piece of rhizome crushed and mixed with small amount of honey can be ingested for treatment of throat pain, cough, common cold, fever and as an antidote in food poisoning. 5 mL of rhizome juice is mixed with 35 mL of *Ocimum basilicum* L. leaf juice and consumed to facilitate blister formation for quick recovery of chickenpox

medicinal properties.

Assam

Assam, situated in one of the biodiversity hotspots, holds a distinctive position in Northeast India. It covers 2.4 % of the country's geographical area, amounting to 78438 sq. km and approximately 35.48 % of the total land area consists of forests. Assam boasts a rich variety of medicinal plants, herbs and the knowledge of their uses is primarily held by the local inhabitants and tribes scattered throughout the region. The state is home to around 300 types of medicinal herbs and plants, with an estimated 5-10 % of them being commercially cultivated for extraction purposes. Many of these plants harbour active ingredients that could potentially be harnessed for the development of novel drugs and pharmaceutical agents, opening new avenues in the field of pharmaceutical sciences for the benefit of humanity (45). Table 8 presents a compilation of several plants employed by local communities in Assam for medicinal purposes.

Sikkim

Sikkim spans an area of 7096 sq. km and exhibits remarkable ecological diversity, encompassing subtropical, temperate, sub-alpine and alpine zones, with the timberline reaching approximately 4000 m. This small region displays pronounced climate fluctuations among various biological zones, promoting a rich and diversified flora. Sikkim is a confluence of ethnicities, comprising over twenty distinct tribes including Bhutias, Lepchas, Limboos, Nepalese and Tibetans. The unique geographical positioning, varied topography, fertile soil, ample rainfall and numerous perennial streams contribute to Sikkim's status as a biodiversity treasure trove in the country. The state boasts a vast reserve of medicinal plants and a rich tradition of folk medicine. The diverse flora of Sikkim includes numerous raw drugs mentioned in ayurvedic texts. In the Sikkim Himalayas region, around 420 plants are utilized by tribal communities for various ailments, with a limited number being commercially exploited (47). Table 9 presents a compilation of several plants employed by local communities in Sikkim for medicinal purposes.

Indigenous medicinal plants to combat emerging and re-emerging health diseases

Emerging and re-emerging transmissible diseases continue to pose significant threats to humanity. Among various infectious

Table 8. Medicinal plants indigenous to Assam and their therapeutic applications (45,46)

Scientific name	Local name	Family	Traditional medicinal uses
Abelmoschus manihot (L.) Medik.	Usipak, Aibika	Malvaceae	The flowers are employed in the treatment of chronic bronchitis and toothache
Abrus precatorius (L.)	Latumoni	Fabaceae	Contributes to hair growth, while the leaves find application in managing fever, cough and cold
Desmodium laxiforum DC.	Bhuterchira	Fabaceae	The leaves and stems are utilized in the treatment of amenorrhea and uterine infections
Thunbergia coccinea Wall.	Changalota, Nillata, Nilakontho	Acanthaceae	The juice extracted from the roots is employed to address stomach infections and issues related to sterility
Spilenthes acmella Murr.	Suhonibon	Asteraceae	The leaves are applied for the treatment of mouth ulcers
Colocasia esculenta (L.) Schott	Kola kochu	Araceae	Consuming corms and runners is thought to be effective in addressing piles and tonsillitis
Calotropis procera (Aiton) W.T. Aiton	Brahmi	Apocynaceae	The juice extracted from the leaves is consumed daily on an empty stomach
Enydra fluctuans Lour	Helechi	Asteraceae	The leaves are employed in the treatment of ringworm
Houttuynia cordata Thunb.	Masandari	Saururaceae	A handful of young shoots and leaves, roasted by wrapping them in a banana leaf and seasoned with a pinch of salt, is consumed as a chutney with meals
Nymphoides indica (L.) Kuntze	Tal japori	Menyanthaceae	The juice extracted from the plant is ingested as a treatment for jaundice

Table 9. Medicinal plants indigenous to Sikkim and their therapeutic applications (48,49)

Scientific name	Local name	Family	Traditional medicinal uses
Aconitum ferox Wall. Ex Seringe	Bikhma	Ranunculaceae	The root serves as an antidote for locally obtained toxic substances. It is pulverized and used to mitigate intense bodily discomfort, diabetes, weakness, asthma, nasal and aural discharge, leprosy, paralysis, rheumatism and typhoid fever. The root is also recognized for its alliterative, diaphoretic, diuretic, expectorant, febrifuge and dyspeptic properties
Aesculus indica (Wall. Ex Cambess.) Hook.	Pangra	Sapindaceae	The powder derived from the seeds is employed to treat mumps, acknowledged for its astringent and anti-inflammatory properties that contribute to toning the walls of the veins
Amaranthus sp. L.	Lali sag	Amaranthaceae	Cooked leaves and shoots are consumed to alleviate symptoms of diarrhoea and dysentery. The oil extracted from the seeds is utilized as a massage oil to provide relief from body aches
Arundinaria maling Gamble	Malingo	Poaceae	Cooked tender shoots are ingested to address stomach problems, particularly stomach ulcers
Cinnamomum tamala (Buch.-Ham.) T. Nees and Nees	Tejpata	Lauracea	Leaves find application in treating colic, rheumatism, diarrhea and scorpion bites
Costus speciosus (J. Koenig) Sm.	Betlauree	Costaceae	Oral administration of the extract from tubers and stems, typically taken before breakfast, is employed to treat urinary tract infections
Eryngium foetidum L.	Lepcha dhania	Apiaceae	The juice derived from the whole plant is administered externally to eradicate bodily parasites and illnesses and to relieve itching
Heracleum wallichii DC.	Chimphing	Apiaceae	Chewing on dried fruits is a method used to address influenza
Piper longum L.	Pipla	Piperaceae	Unripe fruits are alteratives and tonics, whereas mature and dried fruits treat bronchitis, asthma, cough, bile and gall bladder obstructions. Consume mature fruits for its natural, sedative, anthelmintic and abortifacient effects. Muscle sprains are treated with dried seed paste. The oil from ripe fruits treats leprosy. Roots are powerful snakebite remedies
Pteris biaurita L.	Thadayuniu	Pteridaceae	The petiole is crushed and the resultant extract is administered to cuts to cease hemorrhaging and prevent infections

diseases, viral infections are particularly notable, often leading to secondary bacterial and fungal infections that challenge human existence (50). Outbreaks of these viral illnesses have persistently affected worldwide populations, leading to elevated morbidity and mortality rates, particularly in developing and underdeveloped nations. This circumstance mostly results from restricted access to cheap healthcare, inadequate vaccination initiatives and widespread indifference towards immunization. Considering the global prevalence of viral infections and the expense of medications, there is an immediate necessity to devise innovative ways for identifying cost-effective and efficacious antiviral treatments. For instance, the emergence of viral diseases, such as COVID-19, has raised serious health concerns worldwide. According to WHO, while 1813188 COVID-19 deaths were officially reported in 2020, estimates suggest that the true excess mortality may be at least 3000000 (51). Furthermore, since the onset of the HIV epidemic, approximately 88.4 million people have been infected with HIV, resulting in 630000 deaths linked to HIV-related causes in 2023. According to a previous report, approximately 39.9 million people were living with HIV globally by the end of 2023, with 1.4 million being children 0–14 years old and 38.6 million being adults 15 and above (52,53). Additionally, cancer is still one of the top killers on a global scale, with nearly 20 million new cases and 9.7 million deaths attributed to cancer in 2022. Monkeypox has recently gained attention, with 20 cases reported in India in 2022. A national task force has been formed to oversee the development of diagnostics and vaccines (54). The first monkeypox case in India was confirmed on July 14, 2022, after a traveller from the UAE returned to Kerala (55). Currently, there are no specific drugs for treating monkeypox. However, due to its similarity to smallpox, the smallpox vaccine is being explored as a treatment option (56).

To address these challenges, the discovery and development of new pharmaceutical drugs, particularly antiviral and antifungal agents, is an expensive, time-consuming and resource-intensive process. This has prompted the scientific community to explore more accessible and cost-effective alternatives. In this context, medicinal plants have gained increasing attention as they offer a vast reservoir of bioactive compounds that are often safer, more effective and less toxic than synthetic drugs (57). Ethnopharmacology has greatly contributed to the advancement of plant-based medicines and the discovery of new drugs. Traditional herbal medicines, often used by indigenous cultures, have a long history of treating various chronic and infectious diseases. As a result, the search for new antiviral agents now focuses not only on synthetic drugs but also on plant-derived compounds (58). Table 10 presents the various medicinal plants found in the Northeast region that have demonstrated potential and have been tested for their effectiveness as treatments against emerging diseases. There are several plant-based metabolites that can prevent the reproduction of viruses without creating major adverse effects or damaging the host. These all-natural substances may do more than just stop viruses in their tracks; they might even boost the immune system's ability to fight off illnesses. Several medicinal plants have been identified for their strong antiviral properties. Notable among them are *Andrographis paniculata, Lindera chunii, Dioscorea bulbifera, Wistaria floribunda, Xanthoceras sorbifolia* and *Aegle marmelos*, all of which have shown significant anti-HIV activity. Additionally, plants such as *Houttuynia cordata* and *Zingiber officinale* have demonstrated potential against COVID-19 and cancer, while species of *Zanthoxylum* have been traditionally used in the treatment of rheumatism and dengue. Moreover, several chemically diverse substances originating from plants have shown promise as anti-HBV agents (Hepatitis B virus) effects, with some plant-based treatments performing as well as or even better than traditional therapies like interferons or lamivudine (59). Table 10 highlights a range of medicinal plants native to the Northeast region that have shown potential and have been evaluated for their efficacy in treating emerging diseases.

Table 10. Case studies on the potential of some indigenous medicinal plants against various human diseases

Medicinal plant	Disease/tested against	Results	References
Houttuynia cordata Thunb. (HCT) (Fish Mint)	Covid-19 (Corona virus -19) and cytokine storms	Study reported that the plant components, particularly quercetin and kaempferol, shows promise in treating Covid-19 and cytokine storms by targeting multiple proteins	(60)
	HSV (Herpes Simplex Virus)	*Houttuynia cordata* demonstrated a stronger effect against HSV-2 compared to HSV-1, with a lower ED50 for HSV-2	(61)
	SARS-CoV-2 (Severe Acute Respiratory Syndrome Coronavirus2)	The study highlights the potential of bioactive compounds from *Houttuynia cordata* as promising candidates for anti-SARS-CoV-2 drug development, particularly against the RdRp enzyme. The identified compounds demonstrated strong binding affinity and stability, suggesting their suitability for further exploration as therapeutic agents	(62)
	Breast cancer	The results indicate that *Houttuynia cordata* extracts have the potential to significantly reduce the growth of breast cancer cell lines. Cancer cells MCF-7 and MDA-MB-231 through an apoptotic mechanism. The presence of bioactive phytochemicals in the extracts may contribute to their anticancer effects, highlighting the potential of *H. cordata* as a source of therapeutic agents for breast cancer	(63)
	Covid-19	The study analyzed the leaves of *Houttuynia cordata* using Cyclic Voltammetry (CV), Total Phenolic Content (TPC), DPPH assays and Microbial Fuel Cells (MFCs) to evaluate their potential as electron shuttles and their antioxidant properties. Results indicated that the leaf extract is a viable source of electron shuttles, with TPC and DPPH assays confirming that polyphenols contribute significantly to this potential. The study also found that 60 % ethanol extracts had the highest flavonoid content, enhancing bioelectricity generation efficiency. Additionally, molecular docking suggested that quercetin may serve as a potential antiviral agent against Covid-19, linking its antiviral properties to its electron shuttling capabilities	(64)
	Liver cancer	The study showed that hydroalcoholic root extracts of *Houttuynia cordata* can effectively induce apoptosis in liver cancer cells by modulating a specific signalling pathway (the GSK-3β/β-catenin/PDL-1 axis), indicating potential therapeutic applications for cancer treatment	(65)
	Inhibitors of Glutathione Reductase (GR)	Compounds such as quercetin, quercitrin and sesamin demonstrated strong binding affinities and favourable ADME-Tox profiles, highlighting their promise as effective antioxidants. The findings suggest significant therapeutic potential for these phytochemicals in combating various ailments	(66)
	Dengue Virus Serotype 2 (DEN-2)	The plant extract (10-100 µg/mL) significantly reduced intracellular viral RNA and protein expression in HepG2 cells, with an EC50 of 0.8 µg/mL in blocking viral replication. Additionally, it protected against virion release in infected LLC-MK2 cells at concentrations of 10–40 µg/mL. Hyperoside was identified as the main bioactive compound and the extract showed no genotoxic effects on human blood cells	(67)
Zanthoxylum armatum DC. (Indian prickly ash)	Anti-urease effects and SARS-CoV2	This study demonstrates the anti-urease effects of leaf extracts from *Zanthoxylum armatum* and three phenolic compounds, namely chlorogenic acid, trans-ferulic acid and gallic acid. Molecular docking revealed that chlorogenic acid had a strong interaction with *Helicobacter pylori* urease and the coronavirus main protease (Mpro), while gallic acid interacted with SARS-CoV-2 spike proteins	(68)
	Inhibitor of Pyruvate Kinase M2 (PKM2)	A combination of toxicity anticipated anticancer activity and binding affinity led to the identification of three successful compounds: kaempferol, nevadensin and asarinin. Molecular docking showed strong interactions with PKM2's active site, with binding energies ranging from −7.7 to −8.3 kcal/mol. Molecular dynamics simulations confirmed the stability of these compounds in complex with PKM2 and MM-PBSA analysis revealed that nevadensin had the highest binding affinity	(69)
Zanthoxylum piperitum DC. (Fruits) (Japanese pepper)	Rheumatoid Arthritis (RA)	Seven compounds from fruits of *Z. piperium* and eight targets were proposed as potential multi-target strategies for treating rheumatoid arthritis, supporting the clinical efficacy of ZPFs	(70)
Centella asiatica L. (Indian pennywort)	Covid-19	The triterpenoids 2, 3-dihydroxyurs-12-en-28-oic acid, corosolic acid and pomolic acid exhibited the highest binding affinity to the RdRp protein, potentially blocking viral replication. Previous studies have also highlighted the role of triterpenoids in enhancing the immune response *in vitro*	(71)
	Escherichia coli, Bacillus subtilis, Staphylococcus aureus, Salmonella typhi and *Mycobacterium tuberculosis*	The study demonstrated that *Centella asiatica* exhibits antimicrobial activity against these four tested pathogenic bacteria except for *Bacillus subtilis*	(72)
	HIV	The results indicated that silver nanoparticles (AgNPs) synthesized from extracts of *Centella asiatica* may possess potential as an anti-HIV agent, highlighting the need for further investigation into their efficacy and mechanisms of action	(73)
	Autoimmune Inflammatory Diseases	The study found that *Centella asiatica* methanolic extracts effectively inhibited the growth of certain microbes that cause autoimmune inflammatory disorders, while chloroform and hexane extracts effectively inhibited *Klebsiella pneumoniae* growth. Combinations of these extracts with conventional antibiotics showed enhanced effectiveness, restoring significant growth inhibition of *K. pneumoniae* by chloramphenicol and tetracycline. However, certain combinations, particularly with gentamycin, demonstrated antagonistic effects against *Acinetobacter baylyi* and *Streptococcus pyogenes*	(74)

Zingiber officinale Roscoe. (Ginger), *Allium sativum* L. (Garlic)	Covid-19	The study found that chemical constituents from pepper, including piperdardiine and piperanine, as well as compounds from ginger, specifically 8-Gingerol and 10-Gingerol, demonstrated significant activity against Covid-19. The finding also indicate that these plant-derived compounds have the potential to be developed further as antiviral agents against Covid-19	(75)
Curcuma longa L. (Turmeric)	Covid-19	The docking results indicated that turmeric compounds could inhibit key SARS-CoV-2 proteins. Molecular dynamics simulations confirmed the stability of ligand-protein interactions and the ADME properties of the compounds indicated a high likelihood of being drug-like. Overall, the findings suggested that turmeric compounds may serve as therapeutic or protective agents against SARS-CoV-2	(76)
	Cancer	The study discovered that turmeric extracts, when extracted by Microwave-Assisted Extraction (MAE), showed promising anticancer activities at doses ranging from 31.25 to 1000.00 µg/mL, when tested against Huh7 (human liver) and HCT116 (human colon) cancer cell lines.	(77)
Carica papaya L. (Leaves) (Papaya)	Bacterial and fungal infections	Papaya leaf antimicrobial tests showed that 11.4 % methanolic extract inhibited the growth of *Staphylococcus* sp., 10.3 % *Vibrio* sp., 9.7 % E. coli, 9.1 % *Shigella* sp., 9.1 % yeast and 8.3 % *Penicillium* sp. The aqueous extract showed notable inhibition against mold (8 mm). These findings suggested that papaya leaves possess significant antimicrobial properties and could serve as a natural source of antibiotics for treating various bacterial and fungal infections	(78)
Calotropis procera (Aiton) W.T. Aiton (Sodom apple)	Covid-19	The study identified 50 phytochemicals from *Calotropis procera*, evaluating their potential as drugs against the SARS-CoV-2 main protease ADMET analysis and molecular docking revealed 11 phytochemicals with promising drug-like properties, all showing binding affinities of ≥ −4.3 kcal/mol. The top five candidates, namely uscharin, voruscharin, frugoside, coroglaucigenin and benzoylisolineolone demonstrated significant reactivity necessary for interaction with 3CLp. These findings supported further *in vitro* and *in vivo* studies for developing potential drugs targeting SARS-CoV-2	(79)
Cannabis sativa L. (Cannabis)	Covid-19	The study examined the anti-inflammatory activity of *Cannabis sativa* extracts against markers associated with inflammation due to Covid-19 and the study suggested that cannabis extracts may have potential benefits in reducing lung inflammation related to Covid-19, caution is advised in proposing cannabis as a treatment for the disease	(80)
	Cancer	The study investigated the anti-cancer effects of cannabinoids, specifically CBD (Cannabidiol) and THC (Δ9-tetrahydrocannabinol), on Pancreatic Cancer (PC) and they found out that tCBD and THC not only inhibit PC growth but may also enhance immune checkpoint blockade by reducing PD-L1 expression	(81)
Begonia Roxburghii (Miq.)DC.(Leaves) (East Himalayan Begonia)	Analgesic, Anti-arthritic, Thrombolytic and Cytotoxic	According to phytochemical study, *Begonia roxburghii* has a lot of reducing sugars, tannins, alkaloids, glycosides and flavonoids, Following the assays, the study concluded that *Begonia roxburghii* may offer various health benefits, including pain relief, anti-arthritic effects and clot lysis	(82)
Passiflora edulis f. Edulis (Sims) (Passion fruit)	Zika virus	The ethanolic extract of Passion Fruit Seed (PFSE) demonstrated promising anti-Zika virus (ZIKV) activity by reducing viral load and NS1 protein expression in cell lines and human placental explants. PFSE contains bioactive compounds such as piceatannol and naringenin-7-O-glucoside and exhibited strong antioxidant properties. It was well tolerated by cells and effectively protected the placenta from ZIKV infection, positioning it as a potential treatment with further studies required	(83)
Piper longum L. (Indian long pepper), *Piper nigrum* L. (Black pepper), *Terminalia bellerica* (Gaertn.) Roxb. (Baheda), *Terminalia chebula* Retz. (Black Myrobalan) and *Zingiber officinale* Roscoe. (Ginger)	Muscle spasm	The study found that *P. longum* and *P. nigrum* extracts were more effective in reducing spasmogenic contractions compared to other extracts. *T. bellerica* and *Z. officinale* also reduced uterine and intestinal contractions. However, further research on isolated phytochemicals and additional experimental models is needed to confirm their safety and efficacy against spasmogenic induced disorders	(84)
Rubus ellipticus Smith. (Leaves) (Yellow Himalayan raspberry)	Antimicrobial, Anti-arthritis	The Hydroethanolic Extract of *Rubus ellipticus* leaves (HEERE) exhibited significant antimicrobial activity against *Escherichia coli, Staphylococcus aureu* sand *Aspergillus niger.* In anti-arthritis tests on CFA-induced rats, the 200 mg/kg dose was more effective than 50 mg/kg, showing reduced paw volume, joint diameter, leukocyte count and ESR, along with improved body weight, erythrocyte count, hemoglobin levels and synovial healing	(85)
Nepenthes Miranda L. (Pitcher plant)	Cancer	The *N. miranda*-leaf-acetone extract demonstrated notable cytotoxic activity against cancer cell lines, with the strongest effects on B16F10 melanoma, followed by 4T1 mammary carcinoma and PC-9 pulmonary adenocarcinoma cells. Its cytotoxicity was enhanced when combined with the anticancer drug 5 -fluorouracil. Additionally, the extract inhibited the enzyme allantoinase (ALLase), crucial in purine degradation. Plumbagin and stigmast-5-en-3-ol were identified as potential ALLase inhibitors through molecular docking, highlighting the pharmacological potential of *N. miranda* for future medical applications	(64)

Viburnum simonsii Hook and Thomas (Sweet viburnum)	Antioxidant and antimicrobial	The fruit extract demonstrated strong antioxidant activity and effective antimicrobial action against gram +ve bacteria (*Bacillus cereus* and *Staphylococcus aureus*) but showed no activity towards gram -ve bacteria or *Candida albicans*. Phytocompound analysis identified bioactive compounds like neophytadiene, β-sitosterol, α-amyrin and lupeol, which are known for their anticancer, antimicrobial, antioxidant and anti -inflammatory properties, indicating the potential therapeutic value of the extract	(86)
Piper nigrum L.(Black pepper), *Syzygiumaromaticum* (L.) Merr. and L.M. Perry (Clove) and *Zingiber officinale* Roscoe. (Ginger)	Covid-19	Results revealed that guaiol and gingeronone A showed significant inhibitory potential against two key coronavirus protease targets, 6LU7 and 7JTL. These findings suggested that plant-derived compounds, particularly from black pepper, clove and ginger, could play a crucial role in developing therapeutic agents to combat Covid-19	(87)
Moringa oleifera L. (Drumstick tree)	Monkey pox	The study identified riboflavin and ellagic acid as potential inhibitors of DNA polymerase in Monkeypox Virus (MPXV), with both compounds showing excellent stability in molecular dynamics simulations and favourable drug-like properties in ADMET analysis. Gossypetin, while having the highest binding affinity, showed instability. Riboflavin and Ellagic acid are suggested as promising candidates for further experimental validation	(88)

Limitations and challenges

Plant metabolites, which are natural compounds produced by plants, have various therapeutic effects and can work together to provide better treatment results. However, there are challenges in developing these plant compounds into drugs. One of the main issues is their "drugability," which refers to how well a compound can be absorbed, distributed, metabolized and eliminated by the body (known as ADME parameters) (89). Fortunately, new drug delivery systems and nanotechnology offer hope for using plant metabolites as effective drugs. Several of these metabolites have already been developed into new drug delivery systems. However, there are still significant challenges to address, such as obtaining and verifying the quality of plant materials, utilizing high-throughput screening methods to identify active compounds and the complexities involved in isolating and purifying these compounds. Additionally, the potential toxic effects of plant metabolites are often overlooked during laboratory tests but may become apparent during clinical trials. The processes of isolating, purifying and testing pure plant-derived compounds can be intricate, time-consuming and labour-intensive, which can lead to disappointing failures in drug development during clinical trials (90).

Future prospective

Traditional knowledge, particularly in the context of folk medicine from Northeast India, remains largely undocumented, often passed orally through generations. Preserving this knowledge is essential, requiring systematic documentation and exploration of its evolution and the factors contributing to its decline. Such documentation not only aids in protecting intellectual property rights but also supports evidence-based research. Investigating the active ingredients and phytochemicals in medicinal plants offers great potential for discovering new pharmacophores, which could lead to innovative drug targets. Collaborative, multidisciplinary research integrating modern technology and traditional health principles holds promise for global healthcare improvements (10). Around 50000 to 80000 species of flowering plants are utilized for medical purposes globally, as reported by the International Union for Conservation of Nature (IUCN) and the World Wildlife Fund (WWF). 20 % of these species' natural resources have already been practically depleted and some 15000 of these species are in danger of extinction because of habitat loss and over-harvesting (91). The loss of plant species, estimated to be occurring at an accelerated rate, risks the extinction of many medicinal species, particularly in countries like India, China and Kenya (92). Conservation efforts are increasingly urgent, with strategies including both *ex situ* and *in situ* methods. *Ex situ* efforts involve preserving plants outside their habitats, like in seed banks and botanical garden, whereas *in situ* conservation focuses on protecting plants in their natural environments, such as through reserves (Fig. 2) (91,93). These approaches are critical for maintaining the medicinal efficacy and biodiversity of these plants for future use. Between 2001-2020, India experienced a loss of 1.93 million hectares of tree cover, representing a 5 % decline since 2000. Notably, around 1.45 million

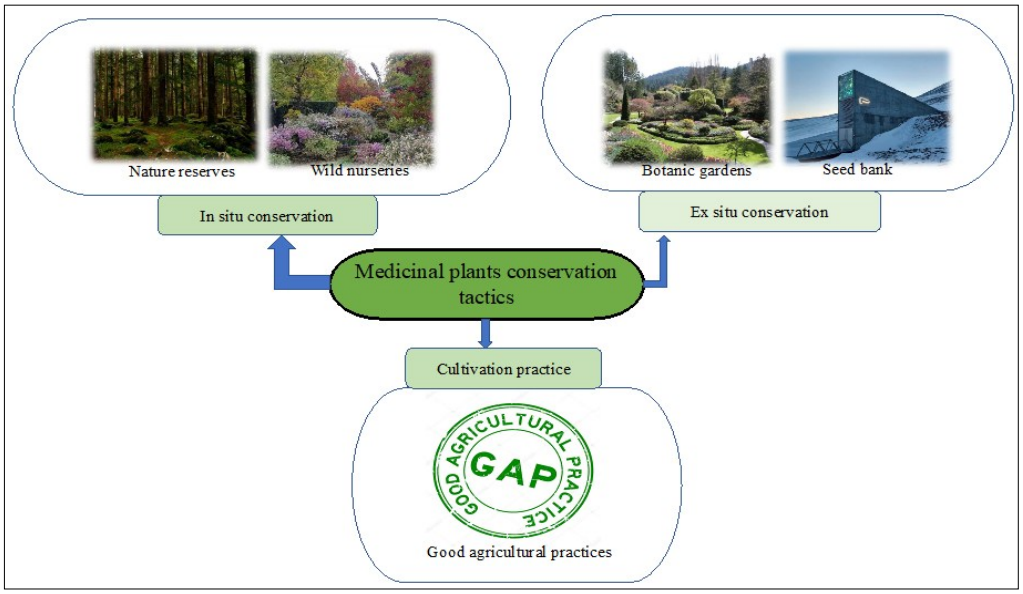

Fig. 2. Methods in flora conservation.

hectares of this loss occurred in the Northeast regions and within this region, Assam was responsible for around 14 % of India's overall tree cover loss from 2001 to 2020, with a reduction of 269 kilo hectares (kha). Following Assam, Mizoram lost 247 kha, Nagaland 225 kha, Arunachal Pradesh 222 kha, Manipur 196 kha, Meghalaya 195 kha and Tripura 102 kha over the two decades (94). Conserving these biodiversity regions is essential, as they could provide new sources for medicines to combat emerging and re-emerging diseases.

Conclusion

Medicinal plants may have a wealth of novel bioactive compounds that can combat both viral and non-viral diseases. By delving into herbal formulations and plants that have not been studied before, ethnomedicinal research can uncover new antiviral compounds that can combat both old and new viruses. Northeast India provides a significant opportunity for ethnobotanical studies, not only due to the richness of its flora but also because of the diverse array of tribes inhabiting the region. For millennia, ancestral people have depended on flora for the remediation of illnesses and the treatment of injuries. The Northeastern states, rich in biodiversity, possess the capacity for substantial contribution to the discovery of new treatments for diseases like cancer, COVID-19, which currently have no definitive cures. Ethnobotanical studies conducted among tribal and rural communities in India have unveiled numerous previously unknown or lesser-known uses of plants. While pharmacologists, pharmacognists and phytochemists have examined only a limited number of plants for their active components, clinical investigations are time-consuming and costly when dealing with many plants. Therefore, ethnobotanical knowledge stands out as a valuable source for preliminary screening in such endeavours. Promoting the responsible management of medicinal plants holds the potential to drive sustainable economic development, ensure affordable healthcare and safeguard crucial biodiversity. To prepare for the future, it is essential to support the cultivation of therapeutic plants. Introducing straightforward, fitting and cost-effective technologies becomes crucial for the sustainable utilization of medicinal plants, facilitated through community-based production centres that aim to preserve traditional knowledge. The state government should compile a catalogue of essential medicinal plant species and establish guidelines for their collection and utilization. The establishment of additional botanical and medicinal plant gardens plays a pivotal role in shielding endangered species. A concerted research effort is needed, with a focus on vulnerable rural communities heavily reliant on medicinal plants for healthcare, as well as those dwelling on the outskirts of forests. This type of research should focus on diversifying livelihood opportunities through the sustainable cultivation of medicinal plants.

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Authors' contributions

ABTM was involved in the conception of work, conducted the literature search, collected data and drafted the manuscript. DS supervised, reviewed, edited and finalized the manuscript. HJW prepared the tables, SR prepared the figures, CSK managed the references and HBS helped in the manuscript revision and plagiarism check. All authors read and approved the final manuscript.

Compliance with ethical standards

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