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REVIEW ARTICLE

Biodiversity and Indigenous Medicinal Knowledge of North-East India: Navigating Climate Change Impacts on Medicinal Plants for Conservation and Advancement

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Abstract

The northeastern region of India holds the sixth position among the world's 25 biodiversity hotspots, covering approximately 8% of the nation's total land area, which amounts to 262,060 square kilometres. Situated in the eastern Himalayas, any alterations in this biodiversity-rich area can have significant and far-reaching consequences. Indigenous tribes of this region believe in the remarkable healing properties of certain medicinal plants, and within its diverse population of around 225 communities, each tribal and sub -tribal group possesses distinct traditional knowledge. Capturing and harnessing this indigenous wisdom by scientists and researchers could unlock new avenues for progress, particularly within the pharmaceutical sector. Climate change stands as one of the paramount global environmental challenges. Predictions indicate that by the close of the 21st century, the Earth's average temperature might rise by anywhere between 0.3 to 4.8 °C, accompanied by a potential sea level increase of 26 to 82 cm. These climate shifts could have adverse effects on the abundance and accessibility of medicinal plants, potentially leading to species extinction. Moreover, the impact of climate change could extend beyond availability to also encompass alterations in the pharmacological properties of various plants, particularly those found in alpine environments. This discussion underscores the importance of existing knowledge, critical analyses, challenges, opportunities, and the immense value of medicinal plants. It emphasizes the intersection of changing climate and the vulnerability of medicinal plant resources, necessitating a comprehensive understanding of these effects in the context of the North Eastern region of India. To address these challenges, there is a pressing need for in-depth research on the geographical distribution of plant communities and strategies to enhance the secondary synthesis of critically endangered medicinal plants under the current climate change scenarios.

Keywords

Medicinal plants, Climate change, Sustainability, Traditional medicine, Indigenous knowledge

Introduction

Ranked 6th among the 25 global hotspots, North-east India covers 262,060 sq. km, accounting for 8% of the nation's land area. This region encompasses eight states: Arunachal Pradesh, Assam, Nagaland, Mizoram, Manipur, Meghalaya, Sikkim, and Tripura, collectively harboring 50% of the nation's

plant biodiversity (1). Situated in the eastern Himalayas, any alterations to this biodiversity hold profound consequences. Researchers suggest that herbal medicines offer a promising avenue, potentially substituting or surpassing synthetic allopathic drugs, even having the potential to supplant them (2). Indigenous tribes of North-east India credit specific medicinal plants with remarkable efficacy against certain diseases. With approximately 225 distinct communities in this area, each tribal and sub-tribal group possesses unique traditional knowledge (3). By effectively documenting this indigenous knowledge, scientists and researchers can pave the way for novel advancements and breakthroughs, particularly within the pharmaceutical sector.

Climate change stands as one of the foremost environmental challenges gripping the world. Projections indicate that the global average temperature could surge by 0.3 to 4.8 °C, and sea levels might elevate by 26 to 82 cm by the close of the 21st century. This phenomenon poses a grave threat to the food and nutritional security of millions, particularly with the impending global population surge from 6.8 billion to 8.3 billion by 2030. As the demand for healthcare, sustenance, water, and industrial resources surges, the strain on the environment intensifies (4). The impact of climate change on medicinal plants and their users is stark, primarily manifested through species extinction. Furthermore, climate change doesn't solely impede the availability and potency of medicinal plants susceptible to its effects, but it also has the potential to alter the pharmacological characteristics of various plants, particularly those thriving in alpine regions (4). In the context of inter-annual timescales, the North-East India rainfall pattern conspicuously deviates from the rest of the nation. The persistent inequality remains evident across extended durations, spanning multiple decades. These findings bear notable consequences when examining historical precipitation records obtained from caves in North-East India (6). A study (7) emphasizes the significance of examining temporal trends in diverse meteorological factors, including rainfall, minimum and maximum temperatures, mean temperature, and mean relative humidity. This analysis is crucial for comprehending the evolving climate trends in North-Eastern India. The research collected meteorological information from 30 monitoring stations, covering the time span of 1971 to 2010. The outcomes of the study indicate that the seasonal shifts in rainfall patterns observed in this region could adversely impact its primarily rain-dependent agricultural practices and biodiversity (Phyto-diversity). Consequently, a re-evaluation of existing crop patterns is imperative to accommodate these changing climatic circumstances.

Mazumder (7) highlights that climate change is posing a significant threat to the survival of approximately 15,000 species of medicinal plants, impacting their natural habitats. To counteract this threat, the cultivation of medicinal plants is gaining traction as a viable strategy for both preserving these plants and their ecosystems, while also catering to the commercial demand for herbal products. This global trend towards cultivation stems from the heightened awareness of environmental sustainability in the 21st century, coupled with an increased focus on health-conscious lifestyles. This is exemplified by the adoption of organic practices and the growing emphasis on green living in contemporary culture. Contrastingly, in northeast India, indigenous knowledge about medicinal plants has been transmitted across generations for decades. The reliance on medicinal plants over conventional pharmaceuticals is rooted in the belief that naturally derived plant medicines, when administered in specific dosages, entail minimal side effects. The essence of this review article lies in summarizing the collective findings of diverse researchers who have studied the repercussions of climate change on medicinal plants. The communication at hand meticulously compiles existing knowledge, conducts an analytical assessment of factors such as phyto-diversity and the significance of medicinal plants, examines the influence of shifting climatic patterns, evaluates the risks posed by climate change on medicinal plants, explores management strategies, delves into recent advancements, and underscores the urgency of further research to comprehensively comprehend the ramifications of climate change in the northeastern region of India.

Phyto-diversity in the North-Eastern states of India

The North-eastern region of India is renowned for its remarkable biological diversity, spanning a diverse range of ecosystems from tropical rainforests to alpine meadows and cold deserts. This area accounts for over 33% of the nation's total biodiversity. The eastern Himalayan region, encompassing Arunachal Pradesh and Sikkim, stands out for its extraordinary biodiversity and has garnered considerable attention from prominent conservation organizations. Conservation International has officially designated all eight states within the north-eastern region as integral parts of the Eastern Himalayan Hotspot (8). The illustration of the states of North east India is given in Figure 1.

This region showcases an exceptional array of plant species, contributing to nearly 50% of India's entire plant species count. Among these are 7,500 flowering plants, 700 orchid species, 63 distinct bamboo species, 64 varied citrus varieties, 28 conifer species, 500 moss species, 700 fern species, and 728 different lichen species that have been meticulously documented within this area. Impressively, more than 200 of the 315 angiosperm families identified in India find representation in the North-Eastern region, underscoring its botanical abundance. Notably, around one-third of the flora inhabiting this region is endemic, signifying their exclusive presence within this specific area. For a visual breakdown of the state-wise phyto diversity across the region (8), please consult Figure 2.

The significance of medicinal plants in North-East India

Sacred groves play a vital role in biodiversity conservation by serving as refuges for endangered species and offering habitats for valuable medicinal and endemic plants. These groves are preserved by indigenous communities, reflecting their strong cultural and spiritual ties to the natural world and underscoring a harmonious coexistence

Figure 1. North east India showing states in sub-sets

between humanity and the environment. Notably, ethnic groups in northeastern India, encompassing Arunachal Pradesh, Meghalaya, Manipur, Assam, and Sikkim, have actively safeguarded forested areas, individual trees, and wildlife due to their ingrained traditional values and profound reverence for the environment. For instance, Arunachal Pradesh has cataloged 101 sacred groves, while Manipur hosts 365, Meghalaya holds 79, Sikkim maintains 35, and the Karbi Anglong district in Assam preserves 40 such groves (9).

Ahmed (10) states that malaria and dengue fever prevail in Tripura communities, primarily transmitted through vectors. Local inhabitants often rely on regionally grown medicinal plants for remedies. Some cultivate indigenous herbs alongside crops, while others gather plant materials from forests. Notably, Tripura follows a unique healthcare practice during Choitro-Songkranti, the Bangla New Year, where consuming leaves from 101 trees is believed to protect against diseases for the year ahead. Ethnobotany highlights the intricate plant-human relationship. The Meitei people of Manipur depend heavily on medicinal plants, integrating cultural practices with plant and animal use, inherited orally. Sacred groves exemplify the interplay between indigenous customs, traditional knowledge, and biodiversity conservation. According to local beliefs, tending to deities ensures protection from illnesses, disasters, and adversities (11).

Changing climate in North east India

In accordance with the IPCC 6th Assessment report (13), approximately 3.3 to 3.6 billion individuals reside in regions highly susceptible to the impacts of climate change, while numerous species also face significant risks. The interconnection between human vulnerability and ecosystem fragility is evident. This relationship is exacerbated by unsustainable developmental patterns, heightening the exposure of both ecosystems and human

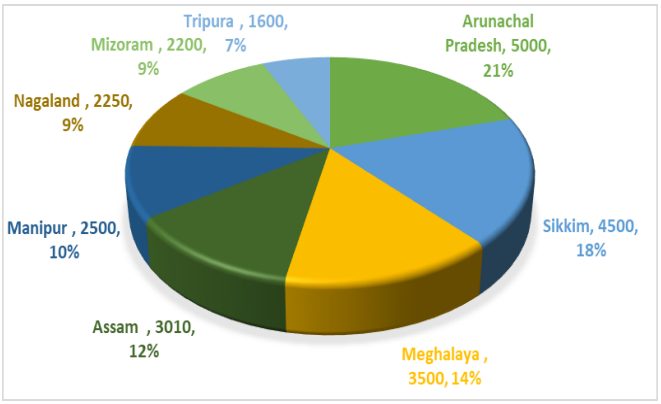

Figure 2. Phyto diversity of North eastern states of India on a state-wise basis (6).

populations to climate-related hazards. The attainment of a 1.5°C global warming scenario in the near future would undoubtedly escalate climate-related dangers, thereby posing substantial threats to both ecosystems and human communities. The severity of these risks hinges on multiple factors, including vulnerability, exposure, socio-economic progress, and adaptation trends. Over the past three decades, Northeast India has experienced diminished rainfall. Notably, there has been an increase in rainfall in several districts of all states except Tripura, where all districts now encounter rain deficits. Atmospheric carbon dioxide concentrations reached their highest levels in three million years in 2020 and continued to rise in 2021. This heightened CO_2 presence has translated into a 1.09-degree Celsius temperature rise since the pre-industrial era. The years 2020 and 2016 shared the record for being the hottest ever recorded, and the decade spanning from 2010 to 2020 stood as the warmest on record. The previous decade (2009-2019) incurred the greatest costs from climate-induced disasters, culminating in substantial economic losses. Shifts in precipitation patterns, particularly during monsoon seasons, are underway, leading to increased aridity in numerous regions. Over the last twenty years, monsoon rainfall has fallen below average in 20 out of 22 years, with a declining trend observable in multiple states. The Northeast region obtains nearly three-quarters of its annual precipitation during the monsoon season, and between 2001 and 2021, this area witnessed subpar rainfall in 19 of the 21 years (13, 14).

Shifting rainfall patterns, particularly within the monsoon season, have substantial repercussions on ecosystems and livelihoods. These changes impact river flows, snow accumulation, and the health of mountain springs, subsequently affecting sectors like agriculture, fishing, forest vegetation, as well as the behavior and habitat of animals and birds. Notably, there is observable evidence of altered river courses in Assam's Lakhimpur and Dhemaji districts. The Subansiri, Dibang, and Brahmaputra rivers, which are tributaries of the Brahmaputra, are undergoing unexpected shifts. The driving forces behind these alterations are sediment mass and momentum, underscoring rivers' essential role as agents of erosion and sediment production. In Manipur, the climate action plan forecasts a temperature surge of

1.7°C by the mid-2030s, coupled with an anticipated 15-19% increase in rainfall during the same period. Similarly, in Nagaland, temperature escalations of 1.6-1.8°C and precipitation upswings of 15-20% are projected between 2020 and 2050. These changes are particularly prominent in districts such as Wokha and Tuensang. Additionally, districts like Phek, Tuensang, and Kohima are expected to face heightened instances of intense rainfall (15).

In Nagaland, a recent report (16) highlights the detrimental impact of heat stress on crop growth, resulting in stunted growth, reduced yields, and the emergence of new diseases and pests. To address these pressing challenges, Nagaland is set to launch a seed exchange program. The program's primary objective is to create field gene banks dedicated to preserving and studying promising crop varieties with various desirable traits. These traits encompass resistance to pests, high yield potential, adaptable cultivation timelines and maturity periods, as well as efficient water usage. According to the most recent national climate vulnerability assessment report, Assam and Arunachal Pradesh are two of the eight Indian states particularly susceptible to the effects of climate change. Arunachal Pradesh, being highly vulnerable, has introduced the "Climate Change Management Mission 2047" as a comprehensive strategy aimed at contributing to global initiatives for reducing and mitigating the impacts of the climate crisis. Responding to the challenges posed by global warming and aiming to enhance both adaptation and mitigation measures, Assam has recently unveiled plans to establish a dedicated department focused solely on climate change (17).

Risk of Climate Change Induced Impact on medicinal plants of North -East India

Medicinal plants hold considerable value in traditional medicine and possess economic significance, but they face substantial threats due to the effects of climate change. This impact is particularly pronounced for plants native to specific geographic regions or ecosystems that are exceptionally susceptible to climate change. One illustrative example is the snow lotus (*Saussurea laniceps*), a medicinal plant found across regions stretching from Sikkim to China. Research highlights that numerous medicinal plant species are exceptionally susceptible due to their endemism to regions or habitats that are especially sensitive to climate change, such as high-altitude areas. There exists substantial empirical evidence indicating that climate change has altered species distribution and the timing of important lifecycle events (phenology), leading to shifts in vegetation patterns. This phenomenon is evident in medicinal plants as well, as they exhibit earlier flowering and changes in their geographical ranges in response to evolving temperature and weather patterns. While appearing as minor adjustments, these seemingly insignificant changes bring forth significant challenges to the survival of these species (18). The investigation (19) centered on the creation of models depicting the potential geographic ranges of *Taxus wallichiana*, taking into account its optimal climatic conditions. The team utilized a reference period spanning from 1960 to 1990 and projected how the species' distribution might alter in the future using climate change scenarios known as representative concentration pathways (RCPs) for the timeframe of 2070. The outcomes unveiled an estimated reduction of 28% (under RCP 4.5) and 31% (under RCP 8.5) in the climatic habitat of *Taxus wallichiana*. These findings accentuate the susceptibility of the species to the consequences of climate change and the possible disturbances that could transpire within mountainous ecosystems.

The forest resources within the northeastern states contribute to approximately 23.75 percent of the total forest cover across the country. This area is characterized by the traditional practice of shifting or jhum cultivation, wherein forest land is temporarily converted into agricultural fields for a brief period. These agricultural activities play a significant role in the fluctuations of the forest cover. Overall, there has been a decrease of 1020 square kilometers in forest cover across the northeastern states (20) refer Table 1. According to information provided in reference (21), *Nardostachys jatamansi*, a medicinal plant native to Sikkim, is classified as critically endangered. Arunachal Pradesh is home to endangered species such as *Aconitum heterophyllum, Bergenia ciliate, Coptis teeta, Homalomena aromatica*, and *Taxus wallichiana*. Particularly, plants indigenous to higher elevations are highly vulnerable to the impacts of climate change due to their specific environmental requirements and limited geographical distribution patterns (22). Residents of Arunachal Pradesh are currently witnessing the consequences of climate change, including shifts in snowfall patterns, temperature alterations, and changes in the timing of plant species' phenology, such as flowering and fruiting seasons. This situation has implications for both medicinal plants and economically valuable plant species in the region. For instance, species like Rhododendron, which thrives in the transition area

Table 1. State-wise Forest cover and medicinal plant wealth in North east India (20)

Sl no.	State	Total Forest Cover (2019)	Total Forest Cover (2021)	Changes in Forest Cover	Medicinal Plant Wealth
1	Arunachal Pradesh	66,688	66,431	-257	500
2	Assam	28,327	28,312	-15	900
3	Manipur	16,847	16,598	-249	1200
4	Meghalaya	17,119	17,046	-73	850
5	Mizoram	18,006	17,820	-186	207
6	Nagaland	12,486	12,251	-235	526
7	Sikkim	3,342	3,341	-1	420
8	Tripura	7,726	7,722	-4	194
	Total	1,70,541	1,69,521	-1,020	4797

between alpine and subalpine ecosystems, could face threats due to their limited capacity for upward range expansion (23). Some important medicinal plant family with the number of species in North eastern states is depicted in Figure 3.

According to reference (24), elevated levels of CO_2 and temperature have been determined to enhance biomass growth. Nevertheless, it is expected that under these circumstances, there might be a reduction in the health-promoting attributes such as total antioxidants, phenols, and flavonoids in *Gynostemma sp*., a medicinal plant documented in Arunachal Pradesh. Another notable species is Taxus wallichiana, located in Sikkim, which serves as a vital source of chemical precursors for producing the anticancer drug paclitaxel. A study referenced as (26) investigates the present and future distribution of *Taxus wallichiana*, a species of significance, with considerations of climate change scenarios. Furthermore, findings from experiment (15) reveal that both drought and heat stress considerably impair the growth and biomass accumulation of *Mentha piperita* and *Catharanthus roseus*, two medicinal plants native to Assam. Nevertheless, these plants exhibit the capability to accumulate osmolytes and secondary metabolites at distinct growth stages in response to stress. This phenomenon suggests that these compounds might ameliorate the adverse effects of drought and heat stress by enhancing plant water potential and scavenging reactive oxygen species. Given the projection of more recurrent droughts and heat waves due to climate change, their combined occurrence is expected to exert more pronounced effects compared to isolated incidences. Drought can arise from reduced precipitation or limited soil water availability, with rising temperatures exacerbating its impacts. Plants have the capacity to acclimate to such conditions through avoidance or tolerance mechanisms. Certain tolerance mechanisms are specific to particular stresses, whereas others are more general and can be activated in response to various stress types, as discussed in reference (27).

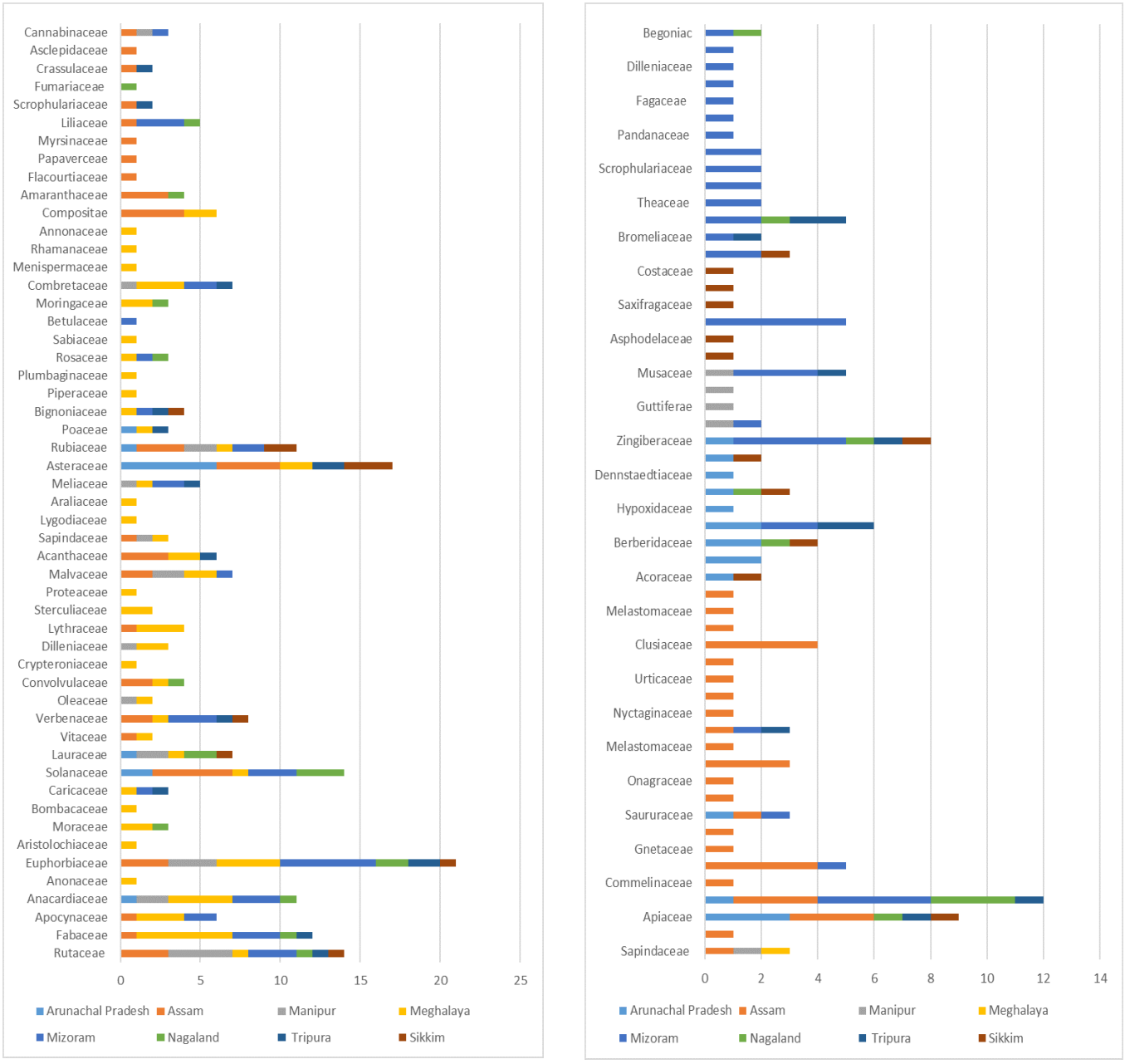

Figure 3. Reporting the North eastern states data of the important medicinal plant family names with the number of species. (22, 23, 24).

Conclusion

The potential of medicinal plants to drive North-eastern advancement is substantial. By integrating these plants into existing traditional practices, innovative, reliable, and sustainable systems can be forged to address global challenges. Particularly in the context of climate change, the effects on the life cycles and distribution of high-altitude plants, predominant in the North-eastern states, are pronounced due to their elevated habitats. To counteract the climate-induced shifts in these medicinal plants, a range of strategic actions can be undertaken. First, encouraging the cultivation of medicinal plants within community gardens can ensure local availability and lessen dependence on wild harvesting. Secondly, preserving and respecting the traditional knowledge associated with these plants not only fosters sustainability but also guides their responsible usage. Thirdly, training harvesters in sustainable techniques, such as selective harvesting and promoting plant regeneration, becomes crucial to prevent overexploitation. Furthermore, endorsing or even mandating certification programs for wild-collected medicinal plant materials, especially within the international trade sphere, can serve to guarantee ethical and sustainable sourcing practices. In addition, the implementation of large-scale conservation initiatives centered on safeguarding habitats becomes pivotal to counter the threats of deforestation and diminishing biodiversity. Lastly, contemplating measures like assisted migration and ex situ seed banking can play a role in preventing the global extinction of invaluable species, albeit with the awareness that these actions might not provide immediate solutions to contemporary community challenges. In summation, a comprehensive strategy encompassing cultivation, knowledge preservation, sustainable practices, certification, conservation efforts, and long-term species protection stands as a potent approach to mitigate the adverse repercussions of a changing climate on medicinal plants in the North-eastern region.

Arunachal Pradesh is particularly susceptible to the impacts of climate change, leading to the introduction of the "Climate Change Management Mission 2047." This initiative serves as a holistic strategy to align with global efforts aimed at curtailing the climate crisis. In response to the escalating challenges posed by rising global temperatures, Assam has recently unveiled plans to establish a dedicated department focused solely on climate change. Presently, there exists an insufficiency of accurate data concerning the precise effects of climate change on medicinal plants within the state. The available information on this subject is limited, underscoring the urgency for more exhaustive data to gain a comprehensive understanding of how climate change is impacting medicinal plant species specifically in the northeastern states of India. Consequently, a more detailed grasp of the variables instigating these changes necessitates the collection of comprehensive and consistent data from representative locations. Hitherto, there is a notable dearth of substantial scientific evidence elucidating the repercussions of climate change on medicinal plants, particularly in the northeastern states. This deficit in scientific backing underscores the immediate requirement to conduct interdisciplinary research and formulate tailored strategies to both adapt to and mitigate the impacts of climate change, specifically tailored to preserve the diversity of medicinal plants.

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Authors' contributions

AC idea, literature search, design and draft; MP literature review, manuscript refinement, coordination; AdC drafting and data analysis; AM design and drafting; AVA literature search; BB literature search.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

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