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Phytochemistry And Ethnomedicine In Climate Resilience

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Abstract : *Climate change continues to exert profound effects on biodiversity, agricultural systems, and human health. Medicinal plants, which provide primary and complementary healthcare for a significant proportion of the global population, are among the most affected biological resources. Altered rainfall patterns, rising temperatures, droughts, and elevated carbon dioxide levels directly influence the growth, survival, and chemical composition of these plants. These environmental changes modify the synthesis of secondary metabolites, which are critical for the pharmacological value of herbal medicines. Ethnomedicine, which encompasses the traditional use of medicinal plants and related cultural knowledge, has historically offered adaptive strategies for sustaining health during environmental fluctuations. This review examines the intersection of phytochemistry and ethnomedicine in strengthening climate resilience. A systematic scoping review approach was employed, involving database searches of Web of Science, Scopus, PubMed, and Google Scholar between 2020 and 2025. Inclusion criteria focused on studies addressing climate change impacts on phytochemistry or ethnomedical practices. The review synthesizes evidence on climate induced shifts in phytochemical profiles, traditional adaptive knowledge systems, and integrative strategies for resilience. Case studies from Nigeria and other African regions are highlighted to demonstrate context specific adaptation practices. Findings show that ethnomedicine complements scientific monitoring by offering ecological indicators, timing strategies, and community based conservation, while phytochemistry provides mechanistic understanding of metabolite fluctuations. Challenges include knowledge erosion, inconsistent phytochemical quality, and limited policy integration. Future directions emphasize the need for transdisciplinary collaborations, omics based monitoring, digital documentation of traditional knowledge, and policies that bridge conservation with cultural heritage. Together, phytochemistry and ethnomedicine form a dual foundation for building climate resilient health systems.*

Keywords: Climate change, Medicinal plants, Phytochemistry, Ethnomedicine, Traditional knowledge, Adaptive strategies, Biodiversity conservation, Nigeria, Africa

1. INTRODUCTION

Climate change has emerged as one of the most pressing challenges of the twenty first century, with consequences that extend across ecological, social, and health domains. It affects biodiversity, agricultural productivity, food security, and human well-being. Among the many biological resources impacted, medicinal plants occupy a particularly critical position. They form the backbone of both traditional medicine and modern pharmaceuticals, contributing significantly to global healthcare. The World Health Organization estimates that nearly 80 percent of the population in developing countries relies on traditional medicine for primary healthcare needs, most of which is plant based. Climate change therefore poses not only an ecological but also a medical and cultural challenge, threatening the sustainability of vital therapeutic resources.

Medicinal plants are highly sensitive to environmental variables such as fluctuations in temperature, altered rainfall patterns, elevated atmospheric carbon dioxide levels, and the increasing frequency of extreme weather events. These changes influence plant physiology, growth rates, geographical distribution, and importantly, the biosynthesis of secondary metabolites. Compounds such as alkaloids, terpenoids, flavonoids, and phenolic compounds are central to the pharmacological properties of medicinal plants, yet their concentrations are often stress-dependent. For example, drought conditions may enhance the accumulation of phenolic compounds as plants mount antioxidant defenses, while excessive heat can suppress alkaloid synthesis. Such shifts may either improve or diminish therapeutic potential, but they invariably introduce uncertainty in the efficacy, safety, and consistency of plant-based remedies (Alum, 2024).

Ethnomedicine, broadly defined as the study and practice of traditional medical systems rooted in cultural, ecological, and spiritual contexts, provides an important counterbalance to the disruptions caused by climate change. For centuries, indigenous and local communities have adapted their knowledge and practices to cope with environmental variability. Through careful observation of ecological indicators, such as flowering times or animal behavior, they are able to predict availability and potency of medicinal plants. Harvesting periods are adjusted to maximize therapeutic quality, and when certain species become scarce, substitutions or new plant combinations are identified. These adaptive practices illustrate resilience and provide valuable insights into sustainable approaches to healthcare under climate stress.

In Nigeria, for instance, ethnomedicinal practices among Yoruba, Igbo, and Hausa communities highlight the integration of ecological awareness with healthcare provision. The neem tree (Azadirachta indica) is widely used for malaria and skin infections, while mango leaves (Mangifera indica) serve in the management of diabetes and gastrointestinal disorders. Bitter leaf (Vernonia amygdalina) is another important species for treating malaria, inflammation, and digestive issues. Despite environmental challenges, these communities continue to rely on a mix of ecological knowledge and cultural practices to preserve the efficacy of such remedies

(Omotayo et al., 2025). Similar patterns can be observed globally, from Andean communities adapting to glacial melt to Asian practitioners responding to monsoon variability, underscoring the universal relevance of ethnomedical adaptation.

By integrating phytochemistry and ethnomedicine, researchers can gain a more holistic understanding of how climate change impacts both the biological foundation and cultural applications of medicinal plants. Phytochemistry provides molecular-level insights into how stress conditions alter biosynthetic pathways and metabolite accumulation, while ethnomedicine captures the lived realities of communities adapting their therapeutic practices. Together, these perspectives reveal not only what is lost under climate pressure but also what forms of resilience emerge. For instance, biochemical monitoring may detect declining alkaloid levels in a medicinal plant, while ethnomedical records may show how healers have shifted to alternative species to preserve treatment outcomes.

This dual lens has important implications for global health policy and sustainable development. It highlights the need for systematic monitoring programs that document both phytochemical changes in key medicinal species and the ethnomedical knowledge systems that buffer against these changes. Documentation, preservation, and respectful integration of indigenous knowledge can complement laboratory-based phytochemical studies, ensuring that adaptation strategies remain effective and culturally grounded.

In addition, climate resilience in healthcare requires a multifaceted approach that combines scientific rigor with cultural sensitivity. Rigorous monitoring of phytochemical changes will allow researchers to track and anticipate alterations in therapeutic efficacy, while preservation of ethnomedical knowledge will safeguard adaptive strategies developed through centuries of lived experience. Special attention to African and Nigerian contexts is particularly important, given the high dependence on medicinal plants and the vulnerability of their ecosystems. By bridging phytochemistry and ethnomedicine, the global community can foster more resilient healthcare systems that withstand the challenges of climate change while honoring the knowledge and practices of local communities.

2. METHODOLOGY

2.1 Research Design

This review followed a systematic scoping methodology inspired by PRISMA guidelines. The purpose was to map the breadth of literature on phytochemistry, ethnomedicine, and climate resilience, and to synthesize findings across diverse geographical contexts.

2.2 Literature Search

Searches were conducted between January and May 2025 using four major databases: Web of Science, Scopus, PubMed, and Google Scholar. Keywords included “phytochemistry and climate change,” “secondary metabolites and medicinal plants,” “ethnomedicine and climate resilience,” “indigenous knowledge and adaptation,” “Nigeria medicinal plants,” and “traditional medicine and climate.” Boolean operators were used to combine terms.

2.3 Inclusion and Exclusion Criteria

- **Inclusion**: peer-reviewed studies from 2020 to 2025 that addressed climate change effects on phytochemical profiles, ethnomedicine and adaptation, or integrative resilience strategies; studies conducted in global, African, or Nigerian contexts; both primary data and systematic reviews.
- **Exclusion**: studies before 2020 unless seminal for background; articles without relevance to medicinal plants or climate; reports without sufficient methodological detail.

2.4 Data Extraction

For each selected study, the following data were extracted: plant species, geographic context, climate variable investigated, phytochemical class affected, ethnomedical adaptation described, and key outcomes. This information was then organized thematically into categories: phytochemical responses, ethnomedical strategies, integration of science and tradition, and policy implications.

2.5 Limitations

Limitations include reliance on English language publications, possible exclusion of unpublished local reports, and heterogeneity of methods across studies. However, by combining multiple databases and including both phytochemical and ethnomedical studies, the review provides a comprehensive overview.

3. EFFECTS OF CLIMATE CHANGE ON PHYTOCHEMICAL PROFILES

Medicinal plants synthesize secondary metabolites in response to environmental pressures, and these compounds often serve as defense mechanisms against herbivores, pathogens, and abiotic stress. Climate change alters many of these conditions simultaneously, introducing complex effects on plant metabolism. As a result, concentrations of bioactive compounds become variable and sometimes unpredictable. This variability has direct implications for therapeutic reliability, drug discovery, and the preservation of ethnomedical practices.

3.1 Alkaloids

Alkaloids such as quinine, morphine, and caffeine are among the most important pharmacologically active natural products. Their biosynthesis is highly sensitive to climatic stressors. Drought and heat stress can either enhance or suppress alkaloid synthesis depending on the plant species and severity of stress. Pant et al. (2025) reported that water deficit conditions stimulated alkaloid accumulation in several Solanaceae species, likely due to activation of stress induced biosynthetic pathways. This aligns with the

ecological role of alkaloids as protective compounds during environmental stress. In contrast, excessive and prolonged heat stress reduced alkaloid levels in Cinchona species, raising concerns about the sustainability of natural quinine production and the efficacy of traditional antimalarial remedies in tropical regions. This highlights the dual and species specific nature of climate impacts, underscoring the need for systematic monitoring of alkaloid rich medicinal plants.

3.2 Flavonoids

Flavonoids are multifunctional metabolites that provide antioxidant activity, anti-inflammatory effects, and photoprotection. They are especially sensitive to ultraviolet radiation, which is intensifying under climate related ozone thinning. Studies consistently show that elevated ultraviolet exposure stimulates higher flavonoid biosynthesis as plants adapt to mitigate oxidative stress (Alum, 2024). In the Nigerian context, Vernonia amygdalina has been observed to produce higher flavonoid concentrations during the dry season when solar intensity is greater, possibly as an adaptive response to harsher conditions (Evbuomwan et al., 2023). While increased flavonoid levels may enhance pharmacological value, the variability across seasons complicates standardization and dosage in herbal therapies.

3.3 Terpenoids

Terpenoids are a chemically diverse group that includes essential oils, saponins, and compounds with antimicrobial, anticancer, and anti-inflammatory activities. Climatic stressors, particularly elevated atmospheric carbon dioxide and water deficit, often promote terpenoid biosynthesis. Research on Azadirachta indica demonstrated that water stress increased concentrations of azadirachtin, the compound responsible for the plant's insecticidal and medicinal activities (Omotayo et al., 2025). This suggests that in some cases, climate stress may enhance ethnomedical efficacy, aligning with traditional practices that favor stressed or mature plants for harvesting. However, not all terpenoid producing plants respond similarly, and prolonged extreme stress may instead suppress growth and compound production.

3.4 Phenolics

Phenolic compounds, including tannins, coumarins, and lignans, are highly responsive to soil nutrient status, water availability, and light intensity. Climate induced soil degradation and nutrient leaching threaten phenolic diversity in many ecosystems. Nonetheless, certain resilient African medicinal plants, such as Alchornea cordifolia, maintain relatively stable phenolic levels even under stressful conditions, ensuring their continued ethnomedical importance (Enyiukwu et al., 2024). This resilience may explain their enduring role in traditional remedies for wounds, infections, and inflammatory conditions. Understanding such stability is critical for identifying "climate-resilient" species that can continue to support healthcare in vulnerable regions.

3.5 Implications

The evidence makes clear that climate impacts on phytochemical profiles are species specific, context dependent, and sometimes contradictory. While certain plants show increased concentrations of valuable compounds under stress, others experience significant declines that reduce pharmacological potency. For researchers, this variability emphasizes the importance of phytochemical monitoring and predictive modeling to anticipate changes in drug quality. For policymakers, it highlights the urgency of conservation strategies to protect species most vulnerable to phytochemical decline. For communities, it reinforces the role of adaptive ethnomedical practices in ensuring continued access to effective remedies.

4. ETHNOMEDICINE AND TRADITIONAL KNOWLEDGE IN ADAPTATION

Ethnomedicine provides cultural strategies that buffer communities against the uncertainties of climate variability. These strategies are grounded in generations of empirical observation and ecological understanding, and they serve as adaptive mechanisms to maintain healthcare resilience.

4.1 Harvest Timing

Traditional communities often adjust harvest seasons based on ecological cues rather than fixed calendars. In Osun State, Nigeria, healers and farmers observe signals such as leaf budding, termite swarms, and bird migrations to identify optimal times for collecting medicinal plants (Agboola et al., 2024). Such ecological knowledge ensures that plants are harvested at peak potency, compensating for seasonal variability in phytochemical content.

4.2 Species Substitution

When climate stress reduces the availability of particular species, communities turn to substitution strategies. In malaria treatment, for instance, Nigerian practitioners substitute Mangifera indica bark with Azadirachta indica leaves when the former is scarce (Evbuomwan et al., 2023). Substitution allows communities to preserve therapeutic continuity while minimizing pressure on overharvested or vulnerable species.

4.3 Mixture Formulations

Polyherbal formulations are another adaptive strategy. By combining multiple plants, healers reduce dependence on the stability of any single species and create synergistic therapeutic effects. In Yoruba medicine, decoctions frequently blend Vernonia amygdalina, Ocimum gratissimum, and Zingiber officinale, providing a buffer against fluctuations in phytochemical concentrations of individual species. These mixtures not only improve resilience but may also enhance overall efficacy.

4.4 Cultural Conservation

Ethnomedicine also embodies conservation ethics. Practices such as selective leaf harvesting rather than uprooting entire plants promote regeneration and long-term availability. In many Nigerian and African communities, taboos and cultural restrictions prevent overharvesting of sacred or medicinally important plants, indirectly supporting biodiversity and resilience of medicinal flora.

4.5 Global Parallels

These adaptive strategies are not unique to Africa. In the Peruvian Amazon, shamans alter collection times in response to seasonal rainfall variability, while in India, Ayurvedic practitioners substitute regionally available plants when climate stress reduces the supply of traditional species. Such global parallels highlight ethnomedicine as a universal reservoir of resilience and adaptability, offering lessons for integrated climate-health responses worldwide.

5. SYNERGY BETWEEN PHYTOCHEMISTRY AND ETHNOMEDICINE

Integrating phytochemistry and ethnomedicine strengthens climate resilience.

5.1 Validation of Traditional Knowledge

Phytochemical studies provide molecular evidence for traditional uses. For example, analysis of Alchornea cordifolia confirmed the presence of flavonoids and alkaloids that justify its ethnomedical use in wound healing and infection management (Enyiukwu et al., 2024).

5.2 Community Based Monitoring

Traditional ecological knowledge informs scientists about plant responses to environmental changes. Local communities observe shifts in taste, color, or aroma of plant extracts, which can correlate with phytochemical alterations.

5.3 Integrative Conservation

Combining phytochemical profiling with ethnobotanical surveys helps identify resilient species for conservation. This dual approach ensures that both biological efficacy and cultural heritage are preserved.

6. CASE STUDIES

6.1 Nigeria: Alchornea cordifolia

Phytochemical profiling in Abia State revealed consistent phenolic content despite seasonal changes, supporting its resilience and continued ethnomedical use (Enyiukwu et al., 2024).

6.2 Nigeria: Uvaria chamae

A 2024 review highlighted anticancer and antimicrobial activity linked to stable phytochemical constituents, reinforcing its value in climate resilience strategies (PubMed Review, 2024).

6.3 Kwara State Ethnobotany

Evbuomwan et al. (2023) recorded adaptive use of multiple plants for malaria, demonstrating substitution and timing strategies to cope with climate variability.

6.4 South Africa

Farmers in Mpumalanga employ ethnobotanical pest management strategies using resilient species, showing the extension of ethnomedicine into agricultural resilience (Shai et al., 2024).

6.5 Amazonian Ethnobotany

Indigenous healers in the Peruvian Amazon report increased potency of certain plants during drought seasons, linking traditional observation with phytochemical adaptation.

7. CHALLENGES AND LIMITATIONS

7.1 Phytochemical Variability

Unpredictable shifts complicate standardization of herbal medicines.

7.2 Knowledge Erosion

Younger generations are increasingly disconnected from traditional knowledge, risking loss of adaptive strategies (Agboola et al., 2024).

7.3 Research Gaps

There is limited longitudinal monitoring of phytochemical responses under real field conditions.

7.4 Policy Disconnection

Current policies rarely integrate climate change, biodiversity conservation, and traditional medicine in a holistic framework.

8. POLICY AND REGULATORY PERSPECTIVES

8.1 Global Strategies

WHO has emphasized the importance of traditional medicine in healthcare resilience. International frameworks also recognize the need to integrate cultural heritage into climate adaptation.

8.2 African Context

The African Union and regional policies call for sustainable medicinal plant use, but implementation remains weak.

8.3 Nigerian Policy

Nigeria's national policy on traditional medicine acknowledges medicinal plant importance but has yet to explicitly address climate resilience.

8.4 Intellectual Property

Ethnomedical knowledge protection under the World Intellectual Property Organization remains critical to prevent exploitation while promoting equitable sharing of benefits.

9. FUTURE DIRECTIONS

- Establishing phytochemical monitoring networks across climate gradients.

- Expanding digital ethnobotany platforms to preserve oral knowledge.
- Applying omics technologies, such as metabolomics and genomics, to identify resilient plant genotypes.
- Promoting community based conservation and participatory research.
- Integrating artificial intelligence and big data for predictive modeling of phytochemical shifts.

10. CONCLUSION

Phytochemistry and ethnomedicine together provide a robust foundation for climate resilience. While phytochemistry reveals the molecular consequences of climate stress on secondary metabolites, ethnomedicine offers culturally rooted adaptive practices that ensure continuity of use. African and Nigerian examples illustrate how communities already employ resilience strategies. Bridging scientific monitoring with ethnomedical knowledge, supported by appropriate policy frameworks, will be essential for sustaining medicinal plant efficacy and protecting cultural heritage in the face of climate change.

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