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Review

Ethnobotanical studies of medicinal plants in Borneo: Bridging tradition and pharmaceutical research

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ABSTRACT

Borneo's rich biodiversity and long-standing traditions of plant-based healing offer a unique convergence of ethnobotany and pharmaceutical research. This review explores the medicinal plants used by indigenous communities in Borneo, emphasizing their role in traditional medicine and their potential for modern pharmaceutical applications. By documenting indigenous knowledge, we highlight key species with proven bioactive properties and examine the growing scientific evidence supporting their efficacy in treating conditions such as inflammation, infection, and chronic diseases. Moreover, we address the challenges of integrating indigenous knowledge with modern scientific research, particularly regarding intellectual property rights, sustainability, and the ethical implications of benefit-sharing. Emerging technologies such as metabolomics, genomics, and artificial intelligence are revolutionizing the field of ethnopharmacology, enabling more efficient identification of bioactive compounds and promoting sustainable harvesting practices. This review calls for increased interdisciplinary collaboration to bridge the gap between traditional medicine and pharmaceutical innovation, as well as the urgent need for conservation efforts to protect Borneo's biodiversity and indigenous knowledge systems. Ultimately, the future of ethnopharmaceutical research in Borneo represents not only an opportunity for drug discovery but also a critical pathway for preserving cultural heritage and advancing sustainable development.

1. Introduction

Ethnobotany is the study of the relationship between people and plants, particularly how indigenous cultures use plants for medicinal, cultural, and spiritual purposes. This field emphasizes the role of plants in traditional medicine, nutrition, and cultural practices (Pei et

Health Sciences International Journal (HSIJ)
Vol. 2, No.2, August 2024, pp. 154 – 168
ISSN: 3026-5037 DOI: https://doi.org/10.71357/hsij.v2i2.41

al., 2020). The integration of indigenous knowledge with modern botanical research has led to the discovery of many pharmacologically active compounds. This interaction between traditional uses and scientific discovery underscores the importance of ethnobotany in identifying plants with potential pharmaceutical applications (de Albuquerque & Hanazaki, 2009).

In traditional medicine, plants have been employed for millennia to treat various ailments. Many indigenous communities rely on an extensive repertoire of local plants to address health issues, making ethnobotany not only a field of cultural importance but also a critical source for discovering new drugs (Balick & Cox, 2020). The transfer of indigenous knowledge from one generation to another has preserved these practices, but modern threats like globalization and habitat destruction are reducing the richness of this knowledge base (Cunningham, 2014).

Borneo, or Kalimantan, the third-largest island in the world, is home to one of the most diverse ecosystems on the planet. It hosts approximately 15,000 species of flowering plants, including 3,000 species of trees and 2,000 species of orchids, making it a biodiversity hotspot (Alhawaris, 2023; Neo et al., 2021; Rajoo et al., 2023). This vast array of plant species offers enormous potential for ethnobotanical studies and the identification of plants with medicinal properties (Adi et al., 2022). The island's rich biodiversity is intricately linked to its cultural diversity, as indigenous groups such as the Banjar, Melayu, Dayak, Iban, and Penan have long relied on Borneo's plants for their health and well-being.

Many plant species found in Borneo are endemic, meaning they do not exist anywhere else on Earth. This uniqueness amplifies the importance of conserving these ecosystems, not only for their ecological value but also for their untapped pharmaceutical potential. Recent ethnobotanical studies have indicated that some of these plants possess anti-inflammatory, antimicrobial, and antimalarial properties, which could be developed into modern medicines (Khan et al., 2023; Mahali et al., 2023; Rajoo et al., 2023; Sutomo et al., 2024). The interconnectedness of biodiversity and ethnobotanical practices in Borneo highlights the importance of preserving both the natural environment and the indigenous knowledge that surrounds it.

The aim of this review is to explore the intersection between indigenous knowledge of medicinal plants and modern pharmaceutical research, particularly within the context of

Health Sciences International Journal (HSIJ)
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ISSN: 3026-5037 DOI: https://doi.org/10.71357/hsij.v2i2.41

Borneo. While ethnobotany provides a foundation for understanding how indigenous people use plants, pharmaceutical research focuses on isolating bioactive compounds for therapeutic use. This review seeks to bridge these two areas, addressing gaps in documentation, scientific validation, and the ethical challenges that arise from utilizing indigenous knowledge in pharmaceutical development (Leonti, 2011).

Borneo's medicinal plant heritage has been under-documented in comparison to other regions of Southeast Asia, presenting a unique opportunity to explore the pharmaceutical potential of its flora (Milow et al., 2017). Furthermore, the lack of standardized methodologies for translating indigenous knowledge into scientific research poses significant barriers to integrating these practices into modern medicine (Domingo-Fernández et al., 2023). Therefore, this review not only highlights the pharmaceutical potential of Bornean plants but also addresses the challenges of preserving indigenous knowledge in the face of modern scientific development.

2. Indigenous knowledge of medical plants in Borneo

Borneo is home to diverse indigenous groups, including the Banjar, Melayu, Dayak, Iban, and Penan communities, each with its own unique healing traditions deeply rooted in the local environment. These indigenous groups rely on their extensive ethnobotanical knowledge, passed down orally through generations, to treat a variety of ailments. For example, the Dayak community employs a wide variety of plants for medicinal purposes. For instance, the Dayak Deah in Pangelak Village use 39 types of medicinal plants for ailments such as back pain, impotence, and fever, with roots being the most commonly used part (Tampubolon et al., 2024). Similarly, the Dayak Maanyan in Lalap Village utilize 36 plant species, with leaves being the most frequently used part (Saputra et al., 2023).

The preservation of this indigenous knowledge is crucial, but it faces threats due to modernization and deforestation. As younger generations move to urban areas and forests are cleared for agriculture and logging, this invaluable ethnobotanical knowledge is in danger of being lost (Ranil et al., 2021). Efforts to document and preserve these practices have been sporadic, yet they are vital for both cultural preservation and scientific exploration.

Borneo boasts a rich repository of medicinal plants that have been traditionally used by indigenous communities. In the Kota Belud District of Sabah, the Sama-Bajau people utilize

Health Sciences International Journal (HSIJ)
Vol. 2, No.2, August 2024, pp. 154 – 168
ISSN: 3026-5037 DOI: https://doi.org/10.71357/hsij.v2i2.41

30 plant species from 22 families for medicinal purposes. Notable families include Arecaceae, Moraceae, and Zingiberaceae. These plants are used in simple treatments involving leaves, rhizomes, and fruits, prepared through methods like boiling and chewing (Mahali et al., 2023). Highly cited plants include *Piper betle*, *Homalomena cordata, Cymbopogon citratus, Curcuma domestica, Kaemferia galanga*, and *Senna alata*, used for treating fever and other conditions. This community's reliance on traditional medicine is declining due to the availability of modern medicine (Hidayani et al., 2023; Meidawati et al., 2024; Rajoo et al., 2023).

In addition to these widely known plants, Bawang Dayak and Pasak Bumi are noted for their anticancer properties. Other plants like *Piper sarmentosum* and *Senna alata* exhibit antimicrobial activity (Alhawaris, 2023; Hussain et al., 2021). These plants are usually prepared in the form of decoctions, poultices, or tinctures, depending on the condition being treated. The knowledge of plant preparation is just as vital as the identification of the species itself, requiring expertise in dosage and plant-part selection.

For many indigenous groups in Borneo, the use of medicinal plants is inseparable from their spiritual beliefs. Plants are not only viewed as healing agents but also as carriers of spiritual energy. The Iban community's taboos, or "pantang larang," are rooted in the belief that violating these customs can lead to misfortune or calamity. These taboos are often associated with symbols such as plants, animals, and actions, which are believed to possess spiritual significance (Rosli et al., 2023). Similarly, rituals conducted before collecting plants are a form of respect and acknowledgment of the spiritual entities believed to inhabit the forest. This practice is mirrored in the Qingyuan Forest–Mushroom Co-cultivation System in China, where respecting forest spirits is a crucial part of ecological conservation (Zhu et al., 2022).

These cultural practices are essential to understanding the full scope of medicinal plant use in Borneo, as they emphasize a holistic approach to healing. The spiritual dimension often dictates when and how certain plants can be used, further illustrating the complexity of indigenous knowledge systems. Recognizing and respecting this cultural context is key to bridging the gap between ethnobotanical research and pharmaceutical development (Cunningham, 2014).

3. Pharmaceutical Potential of Bornean Medicinal Plants

Health Sciences International Journal (HSIJ)
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ISSN: 3026-5037 DOI: https://doi.org/10.71357/hsij.v2i2.41

The pharmaceutical potential of Bornean medicinal plants is a promising area of research, given the rich biodiversity and indigenous knowledge associated with the region. These plants offer a wide array of bioactive compounds with potential therapeutic applications, including anticancer, antimicrobial, and other health-promoting properties. Research into traditional medicinal plants from Sarawak, Malaysian Borneo, has highlighted several species with promising anticancer properties. Notably, extracts *from Piper sarmentosum* and *Orthosiphon aristatus* have shown significant inhibition of nasopharyngeal carcinoma cell lines. This suggests that these plants could be valuable sources of new anticancer agents. The findings from fractionated extracts of these plants indicate their potential to contribute to the development of novel cancer therapies, aligning with the rich tradition of using local flora in traditional medicine. *Piper sarmentosum*, *Piper betle*, and *Senna alata* exhibit significant antimicrobial activity against common pathogens such as *Staphylococcus aureus* and *Escherichia coli*. These plants, traditionally used in local medicine, have shown effectiveness in combating these bacteria, which are often responsible for various infections. Furthermore, *Goniothalamus longistipetes*, another plant from the region, has been found to contain bioactive compounds with broad-spectrum antibacterial activities. This includes effectiveness against drug-resistant bacterial strains, which poses a growing challenge in modern medicine. The presence of these potent compounds in *Goniothalamus longistipetes* underscores the plant's potential as a valuable resource in the fight against antibiotic-resistant infections. Collectively, these findings support the exploration and development of Bornean plants as sources of novel antimicrobial agents (Hussain et al., 2021; Teo et al., 2020).

Seaweeds from North Borneo have been recognized as rich sources of nutraceuticals, offering a range of health benefits due to their antioxidant, anti-inflammatory, and antimicrobial properties. These seaweeds are noted for their protective effects against cardiovascular, neurodegenerative, and renal diseases (Shah et al., 2022). Key bioactive compounds found in these seaweeds, such as fucoxanthin and β-carotene, play a significant role in their therapeutic potential. In addition to seaweeds, indigenous knowledge from Bornean communities has been crucial in identifying medicinal plants with significant health benefits. For instance, *Premna serratifolia*, commonly used in West Kalimantan, has demonstrated antioxidant, antimicrobial, and antidiabetic activities (Khairunnisa et al., 2022).

Health Sciences International Journal (HSIJ)
Vol. 2, No.2, August 2024, pp. 154 – 168
ISSN: 3026-5037 DOI: https://doi.org/10.71357/hsij.v2i2.41

Phytochemical research has led to the isolation of bioactive molecules from such plants, contributing to the development of new therapeutic drugs (Khairunnisa et al., 2022). This combination of traditional wisdom and scientific investigation continues to drive the discovery of novel compounds with potential health benefits.

4. Bridging Tradition and Modern Research

Challenges in integrating indigenous knowledge with pharmaceutical science

One of the main challenges in integrating indigenous knowledge of medicinal plants from Borneo with modern pharmaceutical science is the lack of systematic documentation. Indigenous knowledge is often transmitted orally, making it vulnerable to loss as younger generations adopt modern lifestyles and leave their communities (WHO, 2019). This knowledge gap hampers the ability of researchers to access valuable ethnobotanical information, leading to missed opportunities for drug discovery.

Another critical issue is the scientific validation of traditional medicinal practices. Many traditional uses of plants have not undergone rigorous clinical trials or phytochemical analysis to determine their efficacy and safety (Balick & Cox, 2020). Pharmaceutical research demands standardization and reproducibility, which are difficult to achieve when working with plants that vary in chemical composition due to environmental factors, collection methods, and preparation techniques. This variability complicates the translation of indigenous knowledge into standardized pharmaceuticals.

Intellectual property (IP) concerns also pose significant challenges. The exploitation of indigenous knowledge without proper compensation has led to issues of biopiracy, where pharmaceutical companies commercialize plant-derived compounds without acknowledging or rewarding the communities that provided the knowledge (Wynberg, 2023). These legal and ethical concerns create barriers to collaborative research between indigenous groups and scientists, preventing the fair use and recognition of indigenous knowledge.

Collaborative approaches

Despite these challenges, there have been successful examples of collaboration between indigenous knowledge holders and modern researchers. Collaborative projects such as the Kew Royal Botanic Gardens' ethnobotanical initiative in Southeast Asia have demonstrated the potential for joint efforts to preserve indigenous knowledge while

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ISSN: 3026-5037 DOI: https://doi.org/10.71357/hsij.v2i2.41

advancing pharmaceutical science (Alemu et al., 2024; Andalan et al., 2024). These initiatives often involve working closely with indigenous communities to document their knowledge and ensure they benefit from any pharmaceutical applications developed from their resources.

Partnerships between universities, research institutions, and local communities can lead to mutually beneficial outcomes. By involving indigenous groups in the research process, scientists can gain deeper insights into the cultural context and proper use of medicinal plants. This collaborative approach also helps ensure that indigenous communities receive fair compensation and acknowledgment for their contributions (James & Rajasekharan, 2022; Kate & Laird, 2019).

Governmental and non-governmental organizations (NGOs) play a critical role in facilitating these collaborations. For example, the Sabah Biodiversity Centre in Malaysia has been actively involved in promoting sustainable use of Bornean biodiversity while ensuring equitable benefit-sharing with indigenous communities (Bornean Biodiversity & Ecosystems Conservation, 2021). Such frameworks help create an ethical and sustainable model for bridging indigenous knowledge and modern research.

Ethical considerations

Ethical issues are paramount when it comes to integrating indigenous knowledge into pharmaceutical research. One of the core ethical principles is the concept of prior informed consent, where indigenous communities must be fully informed and agree to any use of their knowledge and resources before research begins (Posey & Dutfield, 1996). This principle ensures that communities retain control over their cultural heritage and are not exploited in the process of commercialization.

Benefit-sharing mechanisms are another crucial ethical consideration. When a medicinal plant from Borneo is developed into a pharmaceutical product, the indigenous communities that provided the knowledge should share in the profits. The Convention on Biological Diversity (CBD) has established guidelines for access and benefit-sharing (ABS) to ensure that benefits are fairly distributed among all stakeholders (Morrison et al., 2021). However, the implementation of these mechanisms remains inconsistent, and many communities still do not receive the compensation they deserve.

Biodiversity conservation is also an ethical concern. The increased demand for medicinal plants can lead to overharvesting and habitat destruction, threatening both the

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ISSN: 3026-5037 DOI: https://doi.org/10.71357/hsij.v2i2.41

plants themselves and the ecosystems they support (Mir et al., 2021). Sustainable harvesting practices must be implemented to protect Borneo's unique biodiversity for future generations while allowing for continued research and development.

5. Future Directions in Ethnopharmaceutical Research

Untapped Potential of Borneo's Flora

Borneo, with its extraordinary biodiversity, continues to be a treasure trove for potential ethnopharmaceutical discoveries. While several medicinal plants have already been studied, there remain numerous species that have yet to be scientifically evaluated. These unexplored plants offer a unique opportunity to expand the frontiers of modern pharmacology. According to Newman and Cragg (Newman & Cragg, 2020), less than 10% of plant species globally have been thoroughly screened for bioactive compounds, suggesting that Borneo's plant diversity could yield new medicinal agents, particularly for treating chronic diseases such as cancer, diabetes, and cardiovascular conditions. The dense forests of Borneo house thousands of endemic plant species, some of which have already demonstrated significant bioactivity in initial screenings but require further study to unlock their full pharmaceutical potential (Sasidharan et al., 2011).

Ethnobotanical research in the region should prioritize cataloging and preserving indigenous knowledge related to these lesser-known plants, especially in collaboration with local communities. Their firsthand experience in utilizing these species provides invaluable insight into which plants might hold therapeutic properties. Moreover, prioritizing species that have yet to undergo phytochemical screening or pharmacological testing could accelerate the discovery of novel therapeutic agents (Balick & Cox, 2020).

Emerging Technologies in Ethnobotanical Research

The advancement of technology offers new tools that can revolutionize ethnopharmaceutical research. Modern techniques such as metabolomics, genomics, and artificial intelligence (AI) can help researchers better understand the complex chemical profiles of medicinal plants and predict their therapeutic potentials. Metabolomics allows for the comprehensive analysis of plant metabolites, providing insight into how various compounds contribute to a plant's medicinal properties (Verpoorte et al., 2005). In the

Health Sciences International Journal (HSIJ)
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ISSN: 3026-5037 DOI: https://doi.org/10.71357/hsij.v2i2.41

context of Borneo's rich biodiversity, metabolomics can rapidly identify bioactive compounds, streamlining the drug discovery process.

Genomics also plays a crucial role in exploring Borneo's medicinal plants. By sequencing the genomes of these plants, researchers can pinpoint specific genes responsible for the biosynthesis of pharmacologically active compounds (Cheng et al., 2021; Y. Pei et al., 2024). This can lead to the development of bioengineered plants or microorganisms that produce these compounds more efficiently, making it easier to mass-produce potential drugs without overharvesting the natural species, a concern raised by conservationists (Cunningham, 2014).

AI-driven research is another promising avenue. Machine learning algorithms can process vast datasets of indigenous knowledge and scientific literature, identifying patterns and predicting which plants are most likely to yield significant pharmacological benefits (Selvaraj et al., 2022). For Borneo, where ethnobotanical knowledge is extensive but scattered, AI could help prioritize plant species for detailed study, potentially reducing the time and resources needed for research.

Sustainable Development and Conservation

Ethnopharmaceutical research in Borneo must balance the need for scientific advancement with the importance of conservation. The region's unique biodiversity is under threat from deforestation, climate change, and unsustainable harvesting practices (Giam et al., 2010). Without careful management, the rapid loss of habitat could result in the extinction of plant species before their medicinal properties are fully understood. Thus, sustainable development practices are essential to ensure that the benefits of Borneo's flora can be enjoyed by future generations.

One approach to sustainability is the cultivation of medicinal plants rather than harvesting them from the wild. This reduces pressure on natural ecosystems and allows for controlled production of bioactive compounds (Shackleton et al., 2009). Additionally, establishing protected areas that preserve both biodiversity and indigenous knowledge is crucial. The integration of ethnobotanical research with conservation efforts could support both pharmaceutical innovation and the preservation of indigenous cultural heritage.

International frameworks, such as the Convention on Biological Diversity (CBD) and the Nagoya Protocol, emphasize the importance of conserving biodiversity while promoting the fair and equitable sharing of benefits arising from the utilization of genetic resources (James

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Vol. 2, No.2, August 2024, pp. 154 – 168
ISSN: 3026-5037 DOI: https://doi.org/10.71357/hsij.v2i2.41

& Rajasekharan, 2022). These frameworks encourage sustainable practices that balance the needs of pharmaceutical research with those of local communities and ecosystems. For Borneo, adherence to these protocols is essential to ensure that research is both ethical and sustainable.

6. Conclusion

The ethnopharmaceutical potential of Borneo's medicinal plants is vast, and the region's biodiversity continues to offer valuable resources for both traditional medicine and modern pharmaceutical research. Throughout this review, we have explored how indigenous knowledge held by indigenous communities provides a critical foundation for discovering novel bioactive compounds. However, the successful integration of this knowledge into pharmaceutical research demands a collaborative and ethical approach that respects the intellectual property rights of indigenous people, promotes sustainable practices, and ensures the fair distribution of benefits.

The challenges in ethnopharmaceutical research—ranging from the lack of scientific validation and documentation to issues of intellectual property—underscore the need for a framework that supports both biodiversity conservation and the ethical utilization of plant resources. Addressing these challenges involves not only local and global collaboration but also the adoption of emerging technologies like metabolomics and genomics. These technologies can accelerate the discovery of new drugs while minimizing the environmental impact of overharvesting Borneo's flora.

As pharmaceutical companies, research institutions, and governments turn to natural sources for new treatments in areas like oncology, inflammation, and infectious diseases, the relevance of Borneo's medicinal plants continues to grow. Moreover, as climate change and deforestation threaten biodiversity worldwide, the urgency to preserve these ecosystems for future ethnopharmaceutical research cannot be overstated. In this context, Borneo's medicinal plants hold great promise for advancing not just the health sciences, but also the fields of sustainability and conservation biology.

To conclude, the future of ethnopharmaceutical research in Borneo hinges on interdisciplinary collaboration between indigenous knowledge holders, researchers, and policymakers. These efforts must be framed within an ethical, sustainable, and scientifically

Health Sciences International Journal (HSIJ)
Vol. 2, No.2, August 2024, pp. 154 – 168
ISSN: 3026-5037 DOI: https://doi.org/10.71357/hsij.v2i2.41

rigorous context to ensure the longevity of both the cultural heritage of indigenous communities and the biodiversity of Borneo. Only through this integrated approach can the full potential of Borneo's medicinal plants be realized in the global quest for novel pharmaceuticals.

7. Conflict of interest

The author declare no conflict of interest.

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