Uluslararası Fen Araştırmalarında Yenilikçi Yaklaşımlar Dergisi
International Journal of Innovative Approaches in Science Research 2025, Vol. 9 (2), 38-58
https://doi.org/10.29329/ijiasr.2025.1330.2

Original article

Phytomedicine in Southeast Asia: Harnessing Biodiversity for Sustainable Healthcare and Economic Growth

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Abstract

The future of phytomedicine in Southeast Asia (SEA) appears promising due to the region's diverse tropical flora, which includes nearly 50,000 known medicinal plants. This review examines current trends in medicinal plant research, the incorporation of phytomedicine into modern healthcare systems, existing challenges, and potential solutions. Recent research has highlighted the therapeutic potential of several notable SEA medicinal plants. Moreover, some countries in the SEA, such as Thailand and Vietnam, have effectively integrated traditional medicine into their modern healthcare systems. By 2026, the herbal medicine market is expected to reach USD 104.78 billion, with Southeast Asia (SEA) playing a significant role in this global economic expansion. However, conservation challenges, methodological complexities, and strict regulatory requirements hinder the practices of phytomedicine. This review emphasizes the importance of international collaboration, technological innovation, and the implementation of sustainable policies in overcoming these challenges. Therefore, phytomedicine has the potential to enhance the global economy, drive healthcare innovation, and promote sustainability by addressing key challenges and harnessing the region's abundant biodiversity.

Keywords: Phytomedicine, SEA, Medicinal Plants, Biodiversity, Traditional Medicine.

Received: 20 March 2025 * **Accepted:** 24 June 2025 * **DOI:** https://doi.org/10.29329/ijiasr.2025.1330.2

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INTRODUCTION

Phytomedicine, sometimes called herbal or botanical medicine, refers to the use of plant parts to treat, prevent, and control diseases (Sam, 2019). Concerns about synthetic medications' adverse effects and resistance have recently sparked a resurgence in interest in phytomedicine as an alternative remedy (Dragos et al., 2017). The cultural and biological diversity of Southeast Asian countries, including the Philippines, Indonesia, Brunei, Myanmar, Cambodia, Vietnam, and Thailand, is well-known and contributes significantly to healthcare services (Kristina et al., 2017). This region is home to an estimated 50,000 plant species, many of which have been essential to traditional medicine due to their promising medicinal properties (Astutik et al., 2019).

Research has shown that SEA's diverse ecosystems, ranging from tropical rainforests to mangroves, serve as a unique repository of medicinal plants (Kristina et al., 2017; Nguyet et al., 2021). These plants have substantial economic implications as the global market for herbal remedies expands (Astutik et al., 2019; Liu, 2021). However, the data regarding their health and economic benefits is often fragmented, necessitating comprehensive reports on the current findings, obstacles, and research gaps in phytomedicine. Consequently, this review examines current trends, including the identification and documentation of medicinal plants, the integration of phytomedicine into healthcare systems, and the commercialization of herbal products. It also highlights obstacles, including regulatory and policy barriers, methodological challenges, and conservation concerns. Additionally, the review explores potential avenues, with a focus on capacity building, education, international collaboration, and technological advancements. The review concludes with a summary of critical points and recommendations for future research and action.

Current Trends in Phytomedicine in SEA

Identification and Documentation of Medicinal Plants in SEA

Ethnobotanical surveys and the preservation of traditional knowledge are crucial for identifying and documenting medicinal plants in Southeast Asia (SEA). These surveys systematically collect data on the utilization of plants for medicinal purposes by Indigenous communities (Benjamin et al., 2021; Ramli et al., 2021). Traditional knowledge, which is often transmitted through generations, provides invaluable insights into the preparation, dosage, and administration of plant-based remedies (Courric et al., 2023).

Recently, there has been a renewed emphasis on documenting this knowledge through ethnobotanical research. These endeavors not only contribute to the preservation of cultural heritage but also serve as a guide for scientific research into the therapeutic potential of these plants (Astutik et al., 2019; Süntar, 2020). Numerous biodiversity hotspots in SEA have been identified as significant sources of medicinal plants. For instance, the forests of Borneo, Sumatra, and the Philippines contain multiple plant species with significant medicinal value (Tiquio et al., 2024; Weiskopf et al., 2019). Researchers in the Malaysian state of Sarawak have discovered a plethora of hitherto unknown plant species that have long been utilized for therapeutic purposes. These findings underscore the importance of these regions in enhancing the global repository of medicinal plants (Haris et al., 2023; Ibrahim et al., 2022).

Integration of Phytomedicine into Modern Healthcare Systems in SEA

SEA has a developing trend toward integrating phytomedicine into modern healthcare systems (Urumarudappa et al., 2019). Several countries in the region have recognized the value of traditional medicine and implemented policies to blend it with conventional healthcare. Thailand, for example, has established the practice of Thai Traditional Medicine, promoting the use of traditional remedies alongside modern treatments. Similarly, Indonesia's Ministry of Health has developed guidelines for incorporating traditional medicine into primary healthcare (Widowati et al., 2020). In Vietnam, the National Institute of Medicinal Materials collaborates with hospitals to integrate traditional herbal medicines into treatment protocols for chronic diseases. This approach has improved patient outcomes and helped reduce healthcare costs (Tran et al., 2022). Malaysia has also made strides in systematically integrating traditional and complementary medicine, aligning policies and administrative methods to ensure effective implementation (Park et al., 2022).

Commercialization and Economic Impact of Phytomedicine in SEA

The commercialization of phytomedicine holds considerable economic promise for SEA. In 2017, the global market for medicinal products was valued at $59.45 billion, according to a report by Business Communications Company (BCC). This market is projected to grow to USD 104.78 billion by 2026, with SEA being a critical contributor. The region's abundant biodiversity and deep-rooted traditional knowledge give it a competitive edge in producing and exporting herbal medicines (Astutik et al., 2019; Sechaba, 2022). For instance, the oil extracted from the seeds of *Scorodocarpus borneensis* has shown great potential as an active ingredient in cosmetics and food preservatives, presenting lucrative opportunities for export from SEA (Wiart et al., 2023).

Pharmaceutical and nutraceutical companies are encouraged to capitalize on this opportunity by developing and marketing products derived from this plant. With its high oil yield, *S. borneensis* is a cost-effective resource that could significantly boost the local herbal industries and contribute to the region's export economy (Wiart et al., 2023). However, the income generated from the commercialization of medicinal plants can fluctuate. For example, in Indonesia, the profit from cultivating *Curcuma xanthorrhiza* ranges from USD 53 to 158 per ton, while in Vietnam, herbal remedies can account for up to 11% of household income (Astutik et al., 2019).

The growing global preference for natural and organic products, driven by increasing health and wellness awareness, has led to a surge in the development of herbal products for marketing purposes. Despite these opportunities, commercialization also brings challenges, including the need for stringent quality control, standardization, and adherence to international regulations (Cunningham et al., 2019; Munugoda K.D. et al., 2022).

Pharmacological Properties of some Medicinal Plants in SEA

Phytochemical research in SEA focuses on identifying and characterizing the bioactive compounds found in medicinal plants. Table 1 summarizes the traditional uses, bioactive compounds, and pharmacological properties of several medicinal plants from the region (Naksen et al., 2022; Thu et al., 2020; Ying et al., 2024). Advanced extraction and identification techniques, such as microwave-assisted extraction (MAE), supercritical fluid extraction (SFE), cold maceration, Soxhlet extraction, high-performance liquid chromatography (HPLC), column chromatography (CC), nuclear magnetic resonance (NMR), mass spectrometry (MS); have greatly enhanced the ability to isolate and identify these bioactive components (Chiriac et al., 2021; Dika et al., 2022). Among the bioactive compounds identified are alkaloids, flavonoids, terpenoids, and polyphenols, all of which demonstrate varying pharmacological properties (Mendoza & Silva, 2018; Mera et al., 2019). For example, curcumin, a compound derived from the turmeric plant (*Curcuma longa*), has been extensively studied for its anti-inflammatory and anticancer properties (Najafi & Khanlarkhani, 2018; Zoi et al., 2021). Similarly, berberine, an alkaloid in several SEA medicinal plants, has shown promising antidiabetic and antimicrobial effects (Utami et al., 2023; Xia et al., 2022). The review encompasses research on the pharmacological properties of some medicinal plants in the SEA region from 2016 to 2025. The databases used for the literature search include Google, PubMed, Google Scholar and Scopus.

Table 1. Some Medicinal Plants in SEA and Their Uses

S. No.	Plant species	Traditional Uses	Major Bioactive Compounds	Therapeutic Potential	Country	References
1	*Curcuma longa*	Anti-inflammatory and wound healing.	Curcuminoid	Anticancer effects were observed in Huh7 and HCT116 cell lines at concentrations ranging from 31.25 to 1000 µg/mL.	Thailand	(Singh et al., 2022)
2	*Andrographis paniculata*	Malaria, snake bites, diabetes, and hypertension	Andrographolide	Antibacterial activity against *Bacillus subtilis, Staphylococcus aureus, Enterococcus faecalis,* and *Escherichia coli* was observed at MIC values of 1.0 to 0.1 mg/mL.	Malaysia	(Banerjee et al., 2017; Liew et al., 2020)
3	*Eurycoma longifolia*	Antihypertensive, sexual dysfunction, anti-ageing, anti-malarial, and anti-diabetic	Quassinoids	The anti-inflammatory effect was observed at an IC_{50} value of 28.18 ± 0.11 µg/mL.	Vietnam	(Thi et al., 2019)
4	*Centella asiatica*	Wound healing, antiacid, asthma, and leprosy.	Triterpenoids (asiaticoside) and phenolic compounds	Antimicrobial effects on bacterial and fungal isolates at 7.81 to 125 mg/mL	Malaysia	(Wong & Ramli, 2021)
5	*Morinda citrifolia*	Antiacid, antidiabetic, pain reliever.	Coumarins (Scopoletin)	Antioxidant activity was observed at IC_{50} values of 172.30 ± 5.23 µg/mL (DPPH).	Vietnam	(Quy & Tan, 2022)
6	*Orthosiphon stamineus*	Urinary tract infection, common cold, fever, edema, and jaundice	Terpenoids, flavonoids, and phenolics (Rosmarinic acid)	Inhibitory effect on protein tyrosine phosphatase 1B, with IC_{50} values between 6.88 and 22.25 µM. Anticancer activity on human breast cancer cell lines, including MCF7, MCF7/TAMR, and MDA-MB-231,	Vietnam	(Dao et al., 2020)

S. No.	Plant species	Traditional Uses	Major Bioactive Compounds	Therapeutic Potential	Country	References
				with IC_{50} values ranging from 8.9 to 21.3 μM.		
7	*Tinospora crispa*	Diabetes management and fever	Alkaloids (berberine), glycosides, terpenes and flavonoids.	The extract demonstrated antidiabetic effects at both high and low doses, specifically 500 mg/kg body weight (BW) and 250 mg/kg BW.	Brunei	(Yusof et al., 2022)
8	*Andrographis paniculata*	Itching, vaginal discharge, anti-pyretic, and anti-diuretic	Andrographolide, quinones, and flavonoids	Antimycobacterial properties against *Mycobacterium tuberculosis* with MIC values of 6.375 mg/mL.	Indonesia	(Asarini et al., 2025)
9	*Piper nigrum*	Analgesic and anti-inflammatory	Phenolics and flavonoids	Antioxidant power at IC_{50} values of 0.214 ± 0.121 and 0.125 ± 0.115 mg/mL for DPPH and ABTS assays, respectively. The anticancer effect was observed in the SW620, HCT116, A549, and H460 cell lines, with IC_{50} values ranging from 58.32 ± 1.902 to 68.22 ± 2.124 μg/mL. Anti-inflammatory activity was observed at concentrations ranging from 40 to 160 μg/mL.	Thailand	(Jongrungraungchok et al., 2023)
10	*Boesenbergia rotunda*	Anti-inflammatory and Gastrointestinal disorders.	Panduratin A	Extract and panduratin A exhibited antiviral activity against SARS-CoV-2, with IC50 values of 3.62 μg/mL and 0.81 μM, respectively.	Thailand	(Kanjanasirirat et al., 2020)
11	*Alpinia galanga*	Skin infections, fever, anti-asthma and digestive aid.	Quercetin	Antioxidant activity was observed at IC_{50} values of 127.67 and 54.82 ppm for DPPH and ABTS, respectively.	Indonesia	(Andriana et al., 2022)

S. No.	Plant species	Traditional Uses	Major Bioactive Compounds	Therapeutic Potential	Country	References
12	*Zingiber officinale*	Antidiabetic, malaise, and gastrointestinal disorders.	Gingerols, shogaols and paradol	Antifungal activity was recorded at concentrations ranging from 15 mg/mL to 60 mg/mL.	Indonesia	(Nuraini et al., 2024)
13	*Mitragyna speciosa*	Pain reliever, stimulant, and fever.	Alkaloid (mitragynine) and phenolic compounds.	Antioxidant activity ranged from 7.94±0.96 μg/mL to 39.49±2.28 mg/mL. The MIC/MBC values for antimicrobial activity ranged from 0.625 to 10 mg/mL. Cytotoxicity effect on breast and colon cancer cell lines, with IC_{50} values ranging from 2.86 to >100 μg/mL.	Malaysia	(Abdul Rahman et al., 2022)
14	*Phyllanthus niruri*	Stomachic, diuretic, and febrifuge.	Lignin compounds (phyllanthin and hypophyllanthin)	Antiviral activity against Hepatitis B Virus, with an IC_{50} value of 170.48 μg/mL.	Indonesia	(Wahyuni et al., 2020)
15	*Alpinia galanga*	Anti-diuretic, anti-ulcerative, pain reliever, and antidiabetic	1,8-cineole, 4-allyphenyl acetate, and α-bisabolene	The essential oil *Alpinia galanga, at doses of 25 mg/mL, 50 mg/mL, and 75 mg/mL, reduced the antibody titer against the* Salmonella antigen.	Indonesia	(Eff & Rahayu, 2016)
16	*Garcinia mangostana*	Skin infections and anti-parasitic	Xanthones, flavonoids, and benzophenones,	Anti-inflammatory properties, with IC_{50} values ranging from 11.72 to 29.81 μM; Antibacterial properties, with MIC values ranging from 1.9531 to 15.625 mg/mL.	Malaysia	(Karunakaran et al., 2019)

S. No.	Plant species	Traditional Uses	Major Bioactive Compounds	Therapeutic Potential	Country	References
17	*Uncaria gambir*	Sore throat, dysentery, and wound healing.	Quercetin, quinic acid, and catechins	Antioxidant activities were observed, with IC50 values of 9.71 µg/mL for DPPH and 6.63 µg/mL for ABTS.	Indonesia	(Hidayati et al., 2022)
18	*Eleutherine palmifolia*	Antihypertensive, and antidiabetic.	Eleutherine and isoeleutherine.	The extract inhibits the growth of lung cancer cells (A549) in two- and three-dimensional culture methods, with an IC_{50} value of 30.01 ± 2.14 µg/mL.	Malaysia	(Zakaria et al., 2023)
19	*Lagerstroemia speciosa*	Weight management, fever, and antidiabetics.	Corosolic acid	Cytotoxicity effect on the MCF-7 cell line at 1.95 to 250 µL	Malaysia	(Banaba et al., 2019)
20	*Murraya koenigii*	Stomachic, digestive disorder, dysentery, and antidiabetic.	Anethole and caryophyllene	Efficacy as an antioxidant with IC_{50} of 95.54 µg/mL (DPPH), 118.12 mg GAE/g extract (ABTS), 48.15 mg GAE/g extract (FRAP). Enzyme inhibition on α-glucosidase with percent inhibition values of 84.55%. Anti-cancer efficacy on human lung cancer cells with inhibition (%) of 80% to 90%.	Thailand	(Tanruean et al., 2021)
21	*Melastoma malabathricum*	Antiacid, diarrhea, and dysentery	Flavonoids (quercetin), alkaloids, and phenolic compounds.	Antimicrobial activity with a zone of inhibition (13 to 27 mm). Antioxidant activity with IC_{50} values between 17.14 and 35.39 µg/mL.	Myanmar	(Hnin et al., 2019)
22	*Ficus deltoidea*	Wound healing and pain relief.	Flavonoids	Wound healing at an extract concentration of 20% in mice.	Indonesia	(Aryani et al., 2020)

S. No.	Plant species	Traditional Uses	Major Bioactive Compounds	Therapeutic Potential	Country	References
23	*Gynura procumbens*	Pain reliever, antihypertensive, and skin diseases.	Quercetin, syringic acid, and kaempferol.	Enzyme inhibition on α-glucosidase with IC_{50} values between 0.064 and 0.244 µg/mL.	Vietnam	(Le et al., 2019)
25	*Clinacanthus nutans*	Snake bites, skin disorders, dysuria, and diarrhoea	Phenols and flavonoids	Antimicrobial activity at 1 mg/mL with ZOI 14 to 15.7 mm on *Pseudomonas aeruginosa.* Wound healing at extract concentrations of 3.91 to 500 µg/mL. The total antioxidant content ranged between 11.96% and 25%.	Malaysia	(Weng et al., 2022)
25	*Vitex trifolia*	Hemorrhoids, rheumatism, and fever.	Alkaloids, flavonoids, phenols, and steroids.	Antibacterial activity against *Klebsiella pneumoniae, Escherichia coli, Staphylococcus epidermidis*, and *Staphylococcus aureus* was observed at 7.5%, 15%, 30%, and 60% with a ZOI of 0.5 to 15 mm.	Indonesia	(Zulkifli et al., 2021)
26	*Cymbopogon citratus*	Microbial infections, fever, and digestive issues.	α and β citral	Antibacterial activity with ZOI 7 mm to 40 mm against gram-positive and gram-negative bacteria.	Malaysia	(Subramaniam et al., 2020)
27	*Pandanus amaryllifolius*	Digestive aid and pain reliever	Octadecenal, Squalene, and phytol.	Antioxidant activity with IC_{50} values of 12.57± 0.45 mg/mL (DPPH).	Thailand	(Yongkhamcha, 2020)
28	*Premna serratifolia*	Antihypertensive and fever	Steroids, caffeic acid, and flavonoids.	Enzyme inhibitory effect against α-glucosidase (98.30%).	Indonesia	(Hadiarti et al., 2021)
29	*Curcuma zedoaria*	Digestive disorders and skin infections	Curcuminoids	The antibiofilm activity against methicillin-resistant *Staphylococcus*	Thailand	(Tabunhan & Tungsukruthai, 2022)

S. No.	Plant species	Traditional Uses	Major Bioactive Compounds	Therapeutic Potential	Country	References
				aureus (MRSA) and methicillin-sensitive *Staphylococcus aureus* (MSSA) was observed, with MIC values of 0.312 mg/mL.		
30	*Cinnamomum verum*	Pain relievers, antidiabetics, and anti-aging products.	Cinnamaldehyde and benzaldehyde	Antimicrobial activity with MIC values between 114.5 ± 10.4 and 146.7 ± 12.5 µg/mL. Anticancer effects on HepG2 and MCF-7 cancer cell lines with IC50 values ranging from 17.5 ± 1.5 to 28.5 ± 2.55 µg/mL.	Vietnam	(Phu et al., 2022)
31	*Orthosiphon aristatus*	Anti-diabetic and antihypertensive.	Flavonoids (Sinensetin) and fatty acids.	Enzyme inhibition against α-glucosidase with IC_{50} values of 43.623 ± 0.039 µg/mL, Antioxidant by ABTS and DPPH assays with IC50 values of 27.556 ± 0.125 µg/mL and 95.047 ± 1.587 µg/mL, respectively.	Indonesia	(Ahda et al., 2023)

Challenges in the Development and Use of Phytomedicine in SEA

Conservation Issues and Sustainability

The sustainable use and conservation of medicinal plants are critical challenges in SEA (Astutik et al., 2019). Overharvesting, habitat loss, and climate change threaten the survival of many plant species. Unsustainable harvesting practices, driven by high demand for medicinal plants, can lead to the depletion of valuable resources (Fierascu et al., 2020). For instance, the overharvesting of the agarwood tree (*Aquilaria* spp.), used in traditional medicine and perfumery, has resulted in its listing as a critically endangered species (Chen et al., 2019). Efforts to address these issues include implementing sustainable harvesting guidelines and cultivation programs, and establishing protected areas (Chen et al., 2019).

Community-based conservation initiatives, where local communities are engaged in the sustainable management of medicinal plant resources, have shown promise in balancing conservation and livelihood needs (Cunningham et al., 2019).

Scientific and Methodological Challenges

Scientific and methodological challenges hinder the development and use of phytomedicine (Karbwang et al., 2019). Standardization and quality control are essential to ensure the safety and efficacy of herbal medicines (Sechaba, 2022). However, the variability in the composition of plant materials, influenced by factors such as geographic origin, harvesting time, and processing methods, poses significant challenges (Thielmann et al., 2019). Therefore, establishing standardized protocols for cultivating, harvesting, and processing medicinal plants is crucial. Clinical trials and efficacy testing of phytomedicines present another set of challenges. Designing and conducting rigorous clinical trials for herbal medicines can be complex due to factors such as the multi-component nature of plant extracts and the variability in patient responses (Parveen et al., 2015). Despite these challenges, applying modern methodologies and guidelines can overcome these issues, highlighting the need for continued investment in phytomedicine (Wink, 2015).

Regulatory and Policy Challenges

Regulatory frameworks and policies significantly impact the development and use of phytomedicine (Sechaba, 2022). Inconsistent regulations and a lack of harmonization across countries can hinder the trade and commercialization of herbal products. For instance, the varying requirements for the registration and approval of herbal medicines across SEA countries create barriers to market entry and expansion (Urumarudappa et al., 2019). Intellectual property rights (IPR) and benefit-sharing mechanisms are critical issues in the context of traditional knowledge and biodiversity. Ensuring Indigenous communities benefit from commercializing their traditional knowledge and resources requires solid legal frameworks and fair benefit-sharing agreements (Astutik et al., 2019). The Nagoya

Protocol on Access and Benefit-sharing, which many SEA countries are parties to, provides a framework for addressing these challenges (Gómez-Castro & Kipper, 2019).

Research Gaps in the Development and Use of Phytomedicine in SEA

The reviewed literature revealed several research gaps (listed below) in the development and application of phytomedicine in SEA. These research gaps highlight the need for a multidisciplinary approach to advancing the field of phytomedicine in SEA, ensuring that it can be sustainably integrated into global healthcare systems while preserving the region's rich biological and cultural heritage.

Biodiversity Conservation

While the SEA is rich in medicinal plant biodiversity, there is a lack of research on effective conservation strategies. The rapid rate of habitat loss and overharvesting of medicinal plants threatens this biodiversity (Chen et al., 2019). Hence, research on sustainable harvesting techniques, the establishment of botanical gardens and seed banks, and the development of community-led conservation programs are needed. Furthermore, research into the impact of climate change on these species and their habitats could be critical in developing long-term conservation strategies (Antons, 2010; Kristina et al., 2017).

Standardization and Quality Control of Herbal Products

The variability in the composition of herbal products due to differences in growing conditions, harvesting times, and processing methods creates challenges in ensuring the consistency and quality of the natural products (Ekor, 2014; Kunle et al., 2012). There is a need for advanced research into standardizing the preparation of herbal medicines, including identifying active compounds, developing quality control protocols, and establishing regulatory standards that ensure product efficacy and safety across batches (Kunle et al., 2012).

Clinical Trials and Pharmacological Validation

Traditional medicinal knowledge is often based on anecdotal evidence, with limited scientific validation through clinical trials (Patwardhan & Mashelkar, 2009; Vickers & Zollman, 1999). Hence, intense pharmacological studies and clinical trials are needed to substantiate the medicinal claims of SEA plants. Research should focus on isolating active compounds, understanding their mechanisms of action, and assessing their efficacy and safety in human populations. This would help bridge the gap between traditional and evidence-based modern medicine (Hamid, Mentor et al., 2014; Yan et al., 2021).

Development and Harmonization of Regulatory Frameworks

The lack of a unified regulatory framework across SEA countries hampers the commercialization and integration of phytomedicine into mainstream healthcare (Urumarudappa et al., 2019); (Sechaba, 2022). Research is needed to develop and harmonize regulatory policies governing the use, production, and marketing of herbal medicines. This includes establishing guidelines for registering, testing, and approving phytomedicine products and ensuring that they meet international standards for safety and efficacy (Urumarudappa et al., 2019).

Documentation and Preservation of Traditional Knowledge

With the passing of older generations, there is a risk of losing invaluable traditional knowledge about medicinal plants and their uses. Hence, there is an urgent need for ethnobotanical research to document and preserve this knowledge. This could involve collaboration with local communities, the use of digital platforms to record and share information, and the development of educational programs that encourage younger generations to learn and preserve traditional practices (Cunningham et al., 2019).

Integration of Modern Technology in Phytomedicine Research

There is a lag in applying modern technologies, such as bioinformatics, genomics, and artificial intelligence, in phytomedicine (Urumarudappa et al., 2019). Research could focus on how these technologies can accelerate the discovery of new medicinal compounds, optimize the production of herbal medicines, and enhance the accuracy and efficiency of phytochemical analysis. For example, AI could be used to predict the pharmacological properties of plant compounds, while genomics could help in understanding the genetic diversity and potential of medicinal plants (Kenshole et al., 2021; Zhang et al., 2012).

Economic and Social Impact Studies

Limited research exists on the socioeconomic impact of phytomedicine, including its role in local economies, public health outcomes, and cultural preservation (Astutik et al., 2019; Sechaba, 2022). Future research could explore the economic benefits of phytomedicine industries for local communities, assess the social acceptance and usage patterns of herbal medicines, and examine how the commercialization of traditional knowledge affects indigenous communities. This would help create sustainable business models that benefit the economy and preserve cultural heritage.

Future Perspectives in Phytomedicine

Technological Advancements and Innovation

Technological advancements and innovation hold great promise for the future of phytomedicine (Lin et al., 2021; Shubham et al., 2018). Biotechnology and genomics offer new tools for the discovery and development of bioactive compounds (Kenshole et al., 2021). Techniques such as genome sequencing, metabolic engineering, and synthetic biology can enhance the production of valuable phytochemicals and facilitate the development of novel therapeutic agents (Kenshole et al., 2021). The development of advanced drug delivery systems, such as nanoparticles and liposomes, can improve the bioavailability and efficacy of phytomedicines (Ahmed et al., 2020). These technologies enable the targeted delivery of bioactive compounds to specific tissues, enhancing their therapeutic effects and reducing side effects. Research in this area is ongoing, with several promising candidates in the pipeline (Ahmed et al., 2020).

Enhancing International Collaboration and Research Networks

Enhancing international collaboration and research networks is essential for advancing phytomedicine in SEA (Cunningham et al., 2019). Collaborative research initiatives can facilitate the sharing of knowledge, resources, and expertise, leading to more comprehensive and impactful studies. Cross-border research partnerships can also address transnational issues such as biodiversity conservation and the sustainable use of medicinal plants (Kristina et al., 2017).

Several frameworks and funding mechanisms support international collaboration in phytomedicine research. For example, the ASEAN Network on Medicinal Plants provides a platform for researchers to collaborate on projects related to the region's conservation, cultivation, and utilization of medicinal plants (Astutik et al., 2019). Similarly, funding programs such as the Global Environment Facility (GEF) and the International Development Research Centre (IDRC) support collaborative research on biodiversity and traditional knowledge (Antons, 2010; Mittermeier & Bowles, 1993).

Education and Capacity Building

Education and capacity building are critical for the sustainable development of phytomedicine. Training and education initiatives can enhance the skills and knowledge of researchers, healthcare professionals, and local communities, thereby improving their capabilities and overall effectiveness. Academic institutions and research organizations play an essential role in providing training programs and educational resources on phytomedicine (Parveen et al., 2015; Sechaba, 2022; Urumarudappa et al., 2019). Building capacity for research and development in phytomedicine requires investment in infrastructure, funding, and human resources. Establishing dedicated research centers, laboratories, and botanical gardens can support the systematic study and conservation of medicinal plants. Additionally, providing scholarships and research grants can encourage young scientists to pursue careers in phytomedicine (Astutik et al., 2019; Jakovljevic et al., 2021).

CONCLUSION

Phytomedicine in SEA offers significant potential due to the region's rich biodiversity and cultural heritage. This review highlights the novel integration of traditional knowledge with modern scientific research, emphasizing how ethnobotanical insights can lead to the discovery of bioactive compounds with therapeutic applications. While integrating phytomedicine into modern healthcare systems has improved patient outcomes and reduced costs, challenges such as conservation, scientific validation, and regulatory hurdles persist. Embracing technological advancements, fostering international collaboration, and investing in education are essential for the sustainable development of phytomedicine. Consequently, SEA can lead significantly in phytomedicine, contributing to global healthcare solutions, a robust economy, and the preservation of natural ecosystems.

Funding source

This study did not receive any funding.

Acknowledgement

We appreciate all the researchers who have contributed to the success of this review paper.

Conflict of interest

The authors declare that they have no conflicts of interest.

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