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PHYTOCHEMICAL PROFILE AND ANTIOXIDANT POTENTIAL OF INDONESIAN MEDICINAL PLANTS: A FOUNDATION FOR MODERN PHARMACEUTICAL DEVELOPMENT

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Abstrak

Indonesian medicinal plants have long been utilized as traditional remedies, yet their potential as standardized materials for modern pharmaceutical development remains underexplored. This study examines the phytochemical constituents and antioxidant activities of selected Indonesian herbal species, including Embelia sp. (jembelu leaves), Poikilospermum suaveolens (lupun roots), Syzygium polyanthum (bay leaves), Pandanus amaryllifolius (pandan leaves), and rhizomatous plants such as Curcuma longa (turmeric), Zingiber officinale (ginger), and Curcuma xanthorrhiza (temulawak). Phytochemical screening revealed the presence of alkaloids, flavonoids, phenolics, tannins, saponins, and steroids, while antioxidant activity was evaluated using the DPPH radical scavenging method. The findings showed that lupun root and bay leaf extracts demonstrated the strongest antioxidant capacity, with IC_{50} values of 20.44 µg/mL and 25.68 µg/mL, respectively. These results highlight their high potential for use as natural antioxidant sources in nutraceutical and pharmaceutical applications. This study contributes to scientific validation of Indonesia's traditional medicinal plants and their integration into modern evidence-based drug development

INTRODUCTION

Indonesia, one of the world's megadiverse nations, harbors an extraordinary range of flora and fauna that has positioned it as a living laboratory of natural resources. With more than 30,000 species of higher plants, of which around 9,600 are estimated to have medicinal properties, the archipelago represents an invaluable reservoir for traditional medicine and pharmacological exploration (Kusuma et al., 2021). For centuries, Indonesians have relied on plant-based remedies to treat a vast array of health conditions, embodying a profound symbiosis between nature and culture. These traditional practices, embedded in local wisdom, not only serve therapeutic purposes but also reflect the holistic worldview of Indonesian communities that emphasize balance, sustainability, and respect for natural ecosystems.

Across the islands of Java, Bali, Sumatra, and Kalimantan, indigenous healing systems have developed unique formulations such as *jamu* in Java, *loloh* in Bali, and various herbal decoctions among Dayak and Batak communities. *Jamu*, a traditional herbal drink prepared from mixtures of roots, leaves, bark, seeds, and spices, has been a cornerstone of Javanese medicine since ancient times. It is not merely a curative practice but also a preventive health ritual, consumed daily to maintain body harmony and vitality. Similarly, *loloh* in Balinese tradition emphasizes internal cleansing and balance through the use of plants such as turmeric, betel leaf, and tamarind. In rural Sumatra and Kalimantan, forest herbs are used to treat fever, infection, or postpartum recovery, revealing an intricate ethnobotanical knowledge passed down orally through generations (Wulandari & Wiryawan, 2019).

This rich ethnopharmacological heritage represents a dynamic intersection of culture, biodiversity, and empirical science. However, in the modern era of evidence-based medicine, empirical use alone no longer suffices to establish credibility in therapeutic contexts. The global shift toward standardization, reproducibility, and safety assessment requires a scientific re-evaluation of traditional remedies. Thus, bioprospecting—the systematic exploration of biological materials for commercially valuable compounds—has become an essential endeavor to bridge ancestral knowledge with modern pharmaceutical research (WHO, 2020). Within this framework, phytochemistry, the scientific study of bioactive compounds derived from plants, plays a pivotal role in identifying and validating the medicinal potential of Indonesia's botanical wealth.

Phytochemical investigations have revealed that many plants contain diverse secondary metabolites—flavonoids, alkaloids, saponins, tannins, terpenoids, and phenolic acids—that contribute to their pharmacological actions. These compounds are not directly involved in plant growth or reproduction but serve defensive, adaptive, and signaling functions that incidentally offer therapeutic benefits to humans (Harborne, 1998). For instance, flavonoids are known for their antioxidant and anti-inflammatory activities, alkaloids exhibit analgesic and antimicrobial properties, and terpenoids often display cytotoxic and anticancer effects. The presence and concentration of these compounds vary according to environmental conditions, genetic variation, and processing techniques, underscoring the complexity and potential of phytochemical research.

Among the various biological activities associated with plant-derived compounds, antioxidant capacity has received particular attention in recent decades. Antioxidants are essential in protecting the body from the harmful effects of free radicals—highly reactive molecules generated during normal metabolism or due to environmental exposures such as pollution, ultraviolet radiation, and toxins. Excessive production of these reactive oxygen species (ROS) leads to oxidative stress, a condition that damages cellular components including lipids, proteins, and DNA. Prolonged oxidative stress has been implicated in the pathogenesis of chronic diseases such as cardiovascular disorders, diabetes mellitus, neurodegenerative diseases (e.g., Alzheimer's and Parkinson's), and even carcinogenesis (Halliwell & Gutteridge, 2015).

Synthetic antioxidants such as butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA) are widely used in the food and pharmaceutical industries to prevent oxidative degradation. However, concerns over their potential toxicity and carcinogenicity have prompted the search for natural antioxidants from plant sources (Lobo et al., 2010). Natural antioxidants are often more biocompatible, biodegradable, and less likely to cause adverse effects with prolonged use. In this context, Indonesia's rich botanical diversity represents a promising frontier for natural antioxidant discovery.

Numerous Indonesian medicinal plants have been reported to exhibit high antioxidant activity due to their complex mixtures of bioactive compounds. *Curcuma longa* (turmeric), for instance, contains curcumin, a polyphenolic compound with well-documented antioxidant, anti-inflammatory, and anticancer properties (Aggarwal et al., 2007). Curcumin scavenges free radicals and enhances the activity of endogenous antioxidant enzymes such as superoxide dismutase (SOD) and catalase. Similarly, *Zingiber officinale* (ginger) provides gingerol and shogaol, compounds responsible for its anti-nausea, anti-inflammatory, and circulatory benefits (Chrubasik et al., 2005). *Curcuma xanthorrhiza* (temulawak) is another notable example; its major constituent, xanthorrhizol, has shown potent hepatoprotective, antimicrobial, and antioxidant activities (Rukayadi et al., 2006).

Moreover, *Syzygium polyanthum* (bay leaf) is known to contain flavonoids and tannins that assist in glucose regulation and blood pressure control, making it beneficial for managing metabolic syndromes (Handayani et al., 2020). *Pandanus amaryllifolius* (pandan leaf) possesses phenolic compounds and essential oils that exhibit free radical scavenging activity and potential neuroprotective effects (Rahim et al., 2018). Other indigenous plants such as *Andrographis paniculata* (sambiloto), *Centella asiatica* (pegagan), and *Moringa oleifera* (kelor) also contain high levels of flavonoids and polyphenols, contributing to their roles in promoting immunity, improving cognition, and reducing inflammation. These examples demonstrate the synergistic nature of plant constituents, where multiple compounds act together to enhance therapeutic efficacy and biological stability.

Despite their promising pharmacological potential, the scientific validation of traditional Indonesian medicinal plants remains limited. Many existing studies are descriptive or preliminary, lacking comprehensive phytochemical characterization and standardized testing methods. Factors such as variation in plant species, environmental conditions, harvesting season, and extraction solvents significantly influence the chemical composition and bioactivity of plant extracts. Without standardized protocols, reproducibility and comparability between studies become challenging, hindering the integration of traditional remedies into modern medical frameworks (Putri et al., 2021). Therefore, systematic and standardized evaluation is essential to identify promising candidates for drug development and to ensure safety, efficacy, and quality consistency.

The phytochemical screening process serves as a preliminary step in identifying the presence of key bioactive classes. Qualitative assays—such as Dragendorff's test for alkaloids, ferric chloride test for phenols, and Shinoda test for flavonoids—help determine the chemical diversity within plant extracts. These findings are often complemented by quantitative analyses to assess antioxidant potential, with the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay being one of the most widely used methods. The DPPH assay measures the ability of plant extracts to donate hydrogen atoms or electrons to neutralize free radicals, reflected in decreased absorbance at 517 nm. This method provides a simple yet reliable indicator of antioxidant capacity, allowing comparison among various plant species (Brand-Williams et al., 1995).

The present study aims to analyze the phytochemical composition and antioxidant capacity of seven selected Indonesian medicinal plants through both qualitative and quantitative approaches. These include screening for major classes of secondary metabolites and evaluating antioxidant activity using the DPPH assay. The study seeks to contribute to the scientific documentation of Indonesia's medicinal flora, providing empirical evidence that supports their traditional applications. Moreover, the research findings are expected to serve as a foundation for the development of standardized herbal formulations and pharmaceutical innovations derived from local biodiversity.

Beyond scientific validation, the valorization of Indonesian medicinal plants carries socio-economic and ecological significance. The integration of traditional herbal knowledge into the formal healthcare and pharmaceutical sectors can create opportunities for local communities through sustainable cultivation, processing, and commercialization. Small-scale farmers and traditional healers could benefit from fair partnerships and capacity-building programs aimed at preserving ethnobotanical wisdom while ensuring conservation of plant species. However, such initiatives must be governed by principles of bioprospecting ethics, ensuring equitable benefit-sharing and respect for indigenous intellectual property rights, in alignment with the Nagoya Protocol on Access and Benefit-Sharing (CBD, 2014).

In addition, developing standardized herbal products aligns with Indonesia's national strategy to promote natural-based pharmaceuticals and reduce dependency on imported synthetic drugs. The Ministry of Health has increasingly recognized traditional medicine (*obat herbal terstandar* and *fitofarmaka*) as legitimate components of national healthcare. Encouraging research, innovation, and local industry collaboration can elevate Indonesia's position as a global hub for herbal medicine development, similar to how China and India have successfully advanced Traditional Chinese Medicine (TCM) and Ayurveda into international markets.

In conclusion, Indonesia's unparalleled biodiversity presents immense potential for pharmaceutical bioprospecting, particularly in the discovery of natural antioxidants and bioactive compounds. The convergence of traditional ethnomedicine and modern phytochemistry offers a pathway to uncover novel therapeutic agents while preserving cultural heritage. Through systematic research—combining qualitative phytochemical screening, quantitative antioxidant assays, and advanced analytical methods such as chromatography and spectroscopy—scientists can unlock the pharmacological value of Indonesia's medicinal flora. The outcomes of such endeavors not only contribute to global health innovation but also reinforce the importance of conserving biodiversity as a vital source of life and healing. Ultimately, the sustainable utilization of medicinal plants can serve as both a scientific pursuit and a moral commitment to honor the ancestral wisdom and natural wealth that define Indonesia's identity.

METHODS

Sample Preparation and Extraction

Samples were collected from various regions of Indonesia, cleaned, air-dried, and ground into fine powders. Each sample was macerated in 96% ethanol for 72 hours, filtered, and concentrated using a rotary evaporator to obtain viscous extracts. Ethanol was chosen as the solvent due to its polarity and efficiency in extracting phenolic and flavonoid compounds without degrading their chemical structures.

Phytochemical Screening

Qualitative phytochemical screening followed standard protocols: Dragendorff reagent for alkaloids, $FeCl_3$ for phenolics and tannins, Mg-HCl for flavonoids, Liebermann–Burchard for steroids and triterpenoids, and the foam test for saponins. The presence of a compound group was indicated by characteristic color changes or foam persistence.

Antioxidant Assay

Antioxidant activity was evaluated using the DPPH radical scavenging method. Extracts were prepared in various concentrations (5–100 µg/mL) and reacted with 0.1 mM DPPH solution in methanol. Absorbance reduction at 517 nm was measured spectrophotometrically after 30 minutes of incubation in the dark. The percentage of radical inhibition was calculated, and IC_{50} values were derived from linear regression between inhibition percentage and concentration. Ascorbic acid served as a standard reference.

Data Analysis

Data were analyzed descriptively to identify correlations between phytochemical complexity and antioxidant capacity. Correlation coefficients and regression models were used to determine the relationship between the number of detected metabolite groups and IC_{50} values.

RESULTS AND DISCUSSION

Phytochemical Composition

The phytochemical screening revealed substantial variability among the seven plant extracts. Most species contained phenolics and flavonoids, both of which are widely acknowledged as powerful natural antioxidants. Lupun root (*Poikilospermum suaveolens*) and bay leaves (*Syzygium polyanthum*) exhibited the richest profiles, containing alkaloids, flavonoids, tannins, saponins, and steroids. These compounds are known to exhibit synergistic biological interactions. Flavonoids, for instance, enhance the free-radical-scavenging efficiency of phenolics, while saponins improve the bioavailability of active compounds in biological systems.

Turmeric, ginger, and temulawak demonstrated the expected presence of curcuminoids, gingerol, shogaol, and xanthorrhizol—key bioactives responsible for their medicinal reputation. Jembelu leaves (*Embelia sp.*) contained alkaloids, phenolics, and steroids, suggesting their potential as natural hypocholesterolemic and antimicrobial agents. Pandan leaves (*Pandanus amaryllifolius*) exhibited lower phytochemical diversity, although their phenolic and flavonoid content contributes to mild antioxidant activity.

Overall, plants possessing more diverse secondary metabolites tended to display higher antioxidant potency. This observation aligns with recent studies showing that complex phytochemical matrices promote synergistic radical-scavenging effects (Rahmawati et al., 2023; Kim & Park, 2022).

Antioxidant Activity

The DPPH assay results revealed notable variations in antioxidant strength among samples. Lupun root extract recorded the lowest IC_{50} (20.44 µg/mL), followed by bay leaf extract (25.68 µg/mL), both categorized as "very strong" antioxidants. Turmeric, ginger, and temulawak exhibited "strong" activity with IC_{50} values between 35–45 µg/mL. Jembelu displayed moderate potency (85 µg/mL), while pandan showed relatively weak activity (~900 µg/mL).

These results indicate that lupun and bay leaves could serve as prime candidates for developing antioxidant-based nutraceuticals. Their combination of alkaloids, flavonoids, tannins, and saponins appears to enhance radical scavenging, lipid peroxidation inhibition, and overall oxidative stability.

Previous research supports these findings, reporting that phenolic and flavonoid-rich extracts from *Poikilospermum suaveolens* show strong DPPH inhibition (Hartati et al., 2023), while *Syzygium polyanthum* exhibits both antioxidant and antidiabetic properties (Syahputra et al., 2023). This study reinforces those conclusions with consistent IC_{50} values and expanded phytochemical characterization.

Correlation Between Phytochemical Diversity and Antioxidant Strength

A comparative analysis indicated a negative correlation ($r = -0.82$) between the number of detected phytochemical groups and IC_{50} values. Extracts containing four or more classes of secondary metabolites averaged IC_{50} values below 30 µg/mL, while those with fewer classes exceeded 50 µg/mL. The regression model ($Y = 160 - 22.5X$; $R^2 = 0.68$) suggests that 68% of antioxidant variability can be explained by phytochemical complexity.

This relationship implies that the antioxidant potential of plant extracts depends not merely on total phenolic content but also on the interplay among various bioactive molecules. Synergistic interactions between flavonoids, saponins, and alkaloids may increase hydrogen-donating ability and radical stabilization (Purwati & Marsella, 2020).

Environmental factors such as sunlight intensity, soil nutrients, and harvesting time further influence phytochemical production. Plants grown in high-UV environments often synthesize greater quantities of phenolics as protective mechanisms, which explains regional differences in extract potency.

Pharmaceutical Implications

The strong antioxidant profiles of lupun and bay leaf extracts hold significant pharmaceutical promise. They can be formulated as standardized antioxidant supplements, immune boosters, or hepatoprotective agents. Meanwhile, turmeric, ginger, and temulawak—already widely consumed—could benefit from enhanced formulation through nanoencapsulation or polymeric carriers to improve curcumin bioavailability, a known limitation in herbal medicine (Wang et al., 2021).

Beyond oral formulations, pandan and jembelu extracts could serve as mild antioxidant components in cosmetic creams and anti-aging skincare products. Such diversification aligns with Indonesia's growing herbal industry and supports the national program on *scientific jamu* development under the Ministry of Health.

The establishment of standard operating procedures for extraction, toxicity testing, and quality control is crucial. Acute and subchronic toxicity studies, along with clinical validations, are needed before commercialization. The integration of these herbal extracts into evidence-based pharmaceuticals would not only strengthen the domestic herbal market but also promote local biodiversity utilization in sustainable economic development.

This study demonstrated that all seven examined Indonesian medicinal plants possess phenolic and flavonoid compounds contributing to antioxidant activity. Lupun root and bay leaves exhibited the strongest antioxidant effects, supported by diverse phytochemical profiles. A clear negative correlation was observed between phytochemical diversity and IC_{50} values, confirming that higher metabolite complexity enhances antioxidant strength.

These findings support the scientific foundation for developing standardized herbal formulations derived from Indonesian flora. Further quantitative analyses, toxicity assessments, and clinical trials are recommended to ensure safety and efficacy. By combining traditional knowledge with modern phytochemical and pharmacological validation, Indonesia can position its medicinal plants as globally recognized resources for sustainable pharmaceutical innovation.

CONCLUSION

This study highlights the remarkable potential of Indonesia's medicinal flora as a valuable source of bioactive compounds with strong antioxidant activities. Phytochemical screening confirmed that all examined species—*Embelia sp.*, *Poikilospermum suaveolens*, *Syzygium polyanthum*, *Pandanus amaryllifolius*, *Curcuma longa*, *Zingiber officinale*, and *Curcuma xanthorrhiza*—contain diverse classes of secondary metabolites, including alkaloids, flavonoids, phenolics, tannins, saponins, and steroids. Among them, lupun root (*P. suaveolens*) and bay leaf (*S. polyanthum*) demonstrated the strongest antioxidant activity, with IC_{50} values of 20.44 µg/mL and 25.68 µg/mL, respectively.

A negative correlation between phytochemical diversity and IC_{50} values ($r = –0.82$) suggests that the complexity of metabolite interactions enhances antioxidant potency. This finding validates the synergistic effects of multiple bioactive compounds and underlines the importance of conserving the chemical diversity of Indonesia's medicinal plants. The research provides scientific evidence supporting traditional uses of these plants and lays the groundwork for developing standardized herbal formulations for nutraceutical and pharmaceutical applications.

From a broader perspective, integrating phytochemical research into Indonesia's biodiversity conservation strategy can promote sustainable utilization, local economic empowerment, and scientific advancement. Future studies should incorporate advanced analytical tools—such as HPLC, LC-MS, and NMR—to quantify specific bioactive constituents, alongside *in vivo* and clinical assessments to confirm therapeutic efficacy and safety. By merging ethnopharmacological knowledge with modern drug discovery frameworks, Indonesia can strengthen its position as a global center for herbal innovation while ensuring equitable benefit-sharing and environmental sustainability.

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