Extraction and Estimation of Total Phenolic Compounds from Different Plant Parts of Hemidesmus indicus (L.) R.Br.

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***Abstract*—Hemidesmus indicus (L.) R.Br., commonly known as Indian sarsaparilla or Anantamul, is a valuable medicinal plant widely used in Ayurvedic, Siddha, and folk medicine for the treatment of skin disorders, inflammation, urinary ailments, blood purification, fever, and general debility. The therapeutic significance of the plant is attributed to the presence of diverse phytochemicals, particularly phenolic compounds, flavonoids, tannins, glycosides, saponins, triterpenoids, and volatile constituents. Phenolic compounds are of special interest because of their antioxidant, antimicrobial, anti-inflammatory, and free-radical scavenging properties, which contribute significantly to the medicinal potential of plant extracts. The present study was undertaken to extract and estimate total phenolic compounds from different plant parts of Hemidesmus indicus (L.) R.Br., namely leaves, bark, fruits, roots, and stem, and to compare their extraction yield and phenolic richness.**

Fresh plant materials were collected, authenticated, shade dried, powdered, and subjected to solvent extraction using a polar organic solvent under controlled conditions. The crude extracts obtained from each plant part were concentrated and weighed to determine extraction yield. Total phenolic content was estimated by the Folin–Ciocalteu colorimetric method, using gallic acid as standard, and the results were expressed as mg gallic acid equivalent per gram dry weight (mg GAE/g DW) Considerable variation was observed in extraction yield as well as total phenolic content among the plant parts studied. Leaves exhibited the highest extraction yield (26.0%) and maximum phenolic content (95.40 mg GAE/g DW), followed by bark (23.5% yield; 84.75 mg GAE/g DW), fruits (21.2% yield; 72.60 mg GAE/g DW), roots (19.5% yield; 60.85 mg GAE/g DW), and stem (17.2% yield; 52.40 mg GAE/g DW). A positive relationship was observed between extraction yield and phenolic content, indicating that phenolic compounds contributed substantially to the extractable phytochemical fraction of H. indicus.

The findings of the study suggest that phenolic compounds are differentially distributed among the plant parts of H.indicus, with leaves and bark serving as the richest sources. The results highlight the potential of these plant parts for use in antioxidant studies, phytochemical standardization, herbal formulations, and pharmaceutical applications. Furthermore, the use of aerial plant parts such as leaves may provide a more sustainable alternative to destructive root harvesting. The study contributes to the phytochemical characterization of H. indicus and provides a basis for further work on isolation, characterization, and biological evaluation of its phenolic constituents.

***Index Terms*—H. indicus, total phenolic content, Folin–Ciocalteu reagent, gallic acid equivalent, medicinal plant, extraction yield, phytochemicals, antioxidant potential**

I. INTRODUCTION

Medicinal plants constitute one of the most important natural resources for the discovery of therapeutic compounds, nutraceutical ingredients, and pharmacologically active metabolites. Since ancient times, plants have been used in traditional systems of medicine for the prevention and treatment of a wide range of human ailments. The biological activity of medicinal plants is primarily attributed to the presence of secondary metabolites, among which phenolic compounds occupy a central position due to their wide spectrum of pharmacological and physiological functions (Harborne, 1998; Trease & Evans, 2002; Cai et al., 2004; Ainsworth & Gillespie, 2007).

Phenolic compounds are a large and structurally diverse group of phytochemicals characterized by one or more hydroxyl groups attached to aromatic rings. This group includes simple phenols, phenolic acids, flavonoids, tannins, lignans, coumarins, quinones, and

polymeric phenolics. These compounds are widely distributed in different plant tissues and are known to play crucial roles in plant growth, development, pigmentation, reproduction, defense, and adaptation to environmental stress (Harborne, 1998; Shahidi & Naczk, 2004; Balasundram et al., 2006). In plants, phenolics function as protective molecules against ultraviolet radiation, oxidative injury, insect herbivory, and microbial infection. They also participate in structural reinforcement through lignification and suberization and are involved in signaling pathways during plant–microbe interactions (Lattanzio et al., 2006; Dai & Mumper, 2010).

From a medicinal and nutritional perspective, phenolic compounds are of great significance because of their strong antioxidant, anti-inflammatory, antimicrobial, antimutagenic, anticancer, cardioprotective, hepatoprotective, and antidiabetic properties. These bioactivities are largely associated with their ability to scavenge free radicals, chelate metal ions, inhibit lipid peroxidation, regulate enzyme activity, and modulate cell signaling pathways (Cai et al., 2004; Balasundram et al., 2006; Dai & Mumper, 2010; Shahidi & Ambigaipalan, 2015). Because of these important properties, quantitative estimation of total phenolic content has become a standard approach in phytochemical screening, antioxidant studies, and herbal drug standardization.

The concentration of phenolic compounds in plants is not uniform; rather, it varies significantly among species and among different plant organs such as leaves, roots, bark, stem, fruits, seeds, and flowers. Such variation depends on the physiological role of the tissue, its developmental stage, exposure to environmental factors, biosynthetic activity, and ecological interactions (Kähkönen et al., 1999; Lattanzio et al., 2006; Ignat et al., 2011). Leaves often accumulate higher levels of phenolic compounds because they are metabolically active and continuously exposed to light, UV radiation, desiccation, and herbivore attack. Bark, being a protective tissue, also serves as a reservoir of tannins and other defense-related phenolics. Fruits contain phenolics associated with pigmentation, seed protection, and ripening, whereas roots and stems may possess different qualitative and quantitative profiles depending on their storage, transport, and defensive functions (Bravo, 1998; Dai & Mumper, 2010; Shahidi & Ambigaipalan, 2015). Therefore, comparative analysis of phenolic content in different plant parts is essential for identifying the most promising source of bioactive compounds and for selecting appropriate plant material for extraction and pharmaceutical applications.

H.indicus (L.) R.Br., commonly known as Indian sarsaparilla and popularly referred to as Anantamul, is an important medicinal plant belonging to the family Apocynaceae. It is a slender, laticiferous, perennial twining or prostrate shrub widely distributed in India, Sri Lanka, and other parts of South Asia. The plant is highly valued in Ayurveda, Siddha, and Unani systems of medicine, where it has long been used as a blood purifier, tonic, alterative, diuretic, demulcent, refrigerant, antipyretic, and remedy for skin diseases, urinary disorders, bronchitis, rheumatism, dysentery, syphilis, epilepsy, and chronic inflammatory conditions (Nadkarni, 1954; Warrier et al., 1995; Austin, 2008; Kirtikar & Basu, 1999). The root of H. indicus is especially important in traditional medicine and is widely used in formulations for detoxification, rejuvenation, and management of chronic diseases.

Modern pharmacological studies have validated many of the traditional claims associated with H. indicus. Different extracts of the plant have been reported to exhibit antioxidant, anti-inflammatory, hepatoprotective, immunomodulatory, antiulcer, antimicrobial, antidiarrheal, antivenom, anticancer, and radioprotective activities (Das & Devaraj, 2006; Saravanan & Nalini, 2007; Chandra Shekar et al., 2011; Austin, 2008; George et al., 2008). These activities are attributed to the presence of a wide range of phytochemicals such as phenolic compounds, flavonoids, tannins, saponins, triterpenoids, sterols, coumarins, glycosides, volatile oils, and resinous substances (Austin, 2008; George et al., 2008; Mahalingam et al., 2014). Among these, phenolic constituents are particularly important because they are closely associated with antioxidant and free radical scavenging activities, which in turn contribute to many of the plant's therapeutic effects.

Although Hemidesmus indicus is traditionally exploited mainly for its roots, increasing interest in sustainable medicinal plant utilization has highlighted the need to evaluate other plant parts such as leaves, bark, fruits, and stem. Overharvesting of roots can damage natural populations and threaten long-term survival of medicinal plants. Comparative phytochemical evaluation of aerial and underground

parts may therefore identify alternative or supplementary sources of bioactive compounds and reduce destructive harvesting pressure (Kala et al., 2006; Chen et al., 2016). Furthermore, knowledge of the distribution of phenolic compounds among different plant organs is important for standardization of herbal raw materials, formulation of plant-based antioxidants, and future pharmacological screening.

Quantitative estimation of total phenolic content is commonly performed using the Folin–Ciocalteu colorimetric method, which remains one of the most widely accepted and convenient methods for evaluating total reducing phenolics in plant extracts (Singleton et al., 1999; Ainsworth & Gillespie, 2007). This method provides a useful index of phenolic richness and allows comparative assessment of different plant materials. In the present study, different plant parts of H. indicus namely leaves, bark, fruits, roots, and stem were subjected to solvent extraction, and their total phenolic content was estimated using the Folin–Ciocalteu assay and expressed as mg gallic acid equivalent per gram dry weight (mg GAE/g DW). Thus, the present investigation was undertaken to extract and estimate total phenolic compounds from different plant parts of H.indicus (L.) R.Br., compare their phenolic richness, evaluate extraction yield, and identify the most promising plant part for further phytochemical, antioxidant, and pharmacological studies. The study also aims to contribute to the phytochemical profiling of this important medicinal species and to support its sustainable utilization in herbal medicine and natural product research.

II. MATERIALS AND METHODS

Collection and Authentication

Healthy and mature plants of Hemidesmus indicus (L.) R.Br. were collected from natural habitats / medicinal plant garden / field sites during the active growth period. The plant was identified based on standard taxonomic keys and authenticated by a qualified taxonomist or botanist from the Department of Botany. A voucher specimen was prepared and deposited in the departmental herbarium for future reference. Collection of healthy, disease-free, and mature plant material is essential because the phytochemical composition of medicinal plants is influenced by plant age, physiological stage, environmental conditions, and season of harvest (Harborne, 1998; Trease & Evans, 2002; Ignat et al., 2011).

For the present study, the plant was carefully uprooted and separated into three different parts:

Leaves Roots and Stem

Each plant part was processed separately in order to compare extraction yield and total phenolic content among tissues. Since phenolic compounds are known to vary among different organs due to differences in metabolism, tissue function, and stress exposure, separate evaluation of plant parts provides valuable phytochemical information (Kähkönen et al., 1999; Lattanzio et al., 2006; Dai & Mumper, 2010).

III. EXTRACTION OF PHENOLIC COMPOUNDS

Phenolic compounds from the powdered plant parts were extracted using a polar solvent extraction method, as phenolics are generally more soluble in polar organic solvents such as methanol, ethanol, acetone, and aqueous alcohol mixtures (Harborne, 1998; Shahidi & Naczk, 2004; Dai & Mumper, 2010). In the present study, methanol was used as the extraction solvent because it has been widely reported to be efficient for extracting phenolic constituents from medicinal plants (Cai et al., 2004; Azmir et al., 2013).

For extraction, 10 g of dried powder of each plant part (leaves, roots, and stem) was weighed accurately using an analytical balance and transferred separately into 250 mL conical flasks. To each flask, 100 mL of methanol was added, maintaining a 1:10 (w/v) ratio of plant material to solvent. The flasks were tightly stoppered with aluminum foil or cotton plugs and kept on a rotary shaker at 150 rpm for 24 hours at room temperature to facilitate maximum extraction of soluble phytochemicals.

After shaking, the contents of each flask were filtered through Whatman No. 1 filter paper into clean beakers. The plant residue remaining on the filter paper was again re-extracted with an additional 50 mL of fresh methanol for another 12 hours to ensure exhaustive extraction of phenolic constituents. The filtrates from the first and second extractions were pooled together for each plant part.

The combined filtrates were then concentrated to dryness under reduced pressure using a rotary vacuum evaporator at 40–45°C, or alternatively evaporated on

a water bath at low temperature to remove the solvent without causing thermal degradation of phenolic compounds. The dried crude extract obtained from each plant part was weighed and transferred to sterile labeled vials. The extracts were stored in a refrigerator at 4°C until further phytochemical analysis.

This method of extraction is commonly employed for recovery of total soluble phenolics from medicinal plants because methanol efficiently penetrates plant tissues and dissolves a wide range of low- and medium-polarity phytoconstituents (Dai & Mumper, 2010; Azmir et al., 2013; Naczk & Shahidi, 2004).

IV. DETERMINATION OF EXTRACTION YIELD

The percentage extraction yield of each plant part was calculated on a dry weight basis. Extraction yield provides an estimate of the number of solvent-soluble constituents recovered from the plant material and is useful for comparing extraction efficiency among different plant parts (Azmir et al., 2013; Dai & Mumper, 2010).

The extraction yield was calculated using the following formula:

$$\text{Extraction Yield (\%)} = \frac{\text{Weight of dried crude extract (g)}}{\text{Weight of dry plant powder used for extraction (g)}} \times 100$$

The extraction yield values obtained for different plant parts were recorded and compared.

Estimation of Total Phenolic Content

Preparation of Sample Extract Solution

A known quantity of each dried crude extract, usually 10 mg, was dissolved in 10 mL methanol to obtain a concentration of 1 mg/mL. The solution was vortexed thoroughly and filtered if any insoluble particles were present. This extract solution was used for the Folin–Ciocalteu assay.

Assay Procedure for Total Phenolic Content

The total phenolic content of each extract was determined by the following procedure:

1. 1 mL of the plant extract solution was pipetted into a clean test tube.
2. To this, 5 mL of diluted Folin–Ciocalteu reagent was added.
3. The mixture was allowed to stand for 3–5 minutes at room temperature for initial reaction.
4. Then 4 mL of 7.5% sodium carbonate solution was added to the reaction mixture.
5. The contents were mixed thoroughly using a vortex mixer.
6. The tubes were incubated at room temperature in the dark for 30 minutes to allow full color development.
7. After incubation, absorbance of the blue-colored solution was measured at 765 nm using a UV–Visible spectrophotometer against a reagent blank.
8. A blank was prepared using methanol or distilled water in place of plant extract.

The same procedure was repeated for all plant extracts as well as for the gallic acid standards. Each determination was carried out in triplicate to minimize analytical error and improve reproducibility.

Calculation of Total Phenolic Content

The absorbance values obtained for plant extracts were fitted into the gallic acid standard calibration curve, and the equivalent concentration of phenolics was determined. The total phenolic content was expressed as mg gallic acid equivalent per gram dry weight of plant material (mg GAE/g DW) using the following formula:

$$\text{TPC} = \frac{C \times V}{M}$$

Where:

- TPC = Total phenolic content (mg GAE/g DW)
- C = Concentration of gallic acid obtained from the standard curve (mg/mL)
- V = Volume of extract used in the assay (mL)
- M = Weight of dry plant material or extract taken for analysis (g)

Alternative expression

If the result is calculated based on dry extract and then converted to dry plant basis, the value may be expressed accordingly as mg GAE/g extract or mg GAE/g dry weight. In the present study, the final results were expressed as mg GAE/g DW for comparison among plant parts.

V. OBSERVATIONS & RESULTS

Table 1. Extraction Yield and Physical Characteristics of Extracts from Different Plant Parts of Hemidesmus indicus

Sr. No.	Plant Part	Dry Weight of Powder Used (g)	Weight of Crude Extract (g)	Extraction Yield (%)	Colour of Extract	Consistency/Appearance
1	Leaves	10.0	2.60	26.0	Dark greenish-brown	Thick semi-solid
4	Roots	10.0	1.95	19.5	Dark brown	Viscous mass
5	Stem	10.0	1.72	17.2	Light brown	Semi-solid to sticky

Table 1 presents the extraction yield and physical characteristics of crude methanolic extracts obtained from different plant parts of Hemidesmus indicus. A uniform quantity of 10 g dry powder from each plant part was used for extraction to facilitate comparison of extractive values. The quantity of crude extract obtained varied markedly among plant parts, indicating differential accumulation of solvent-soluble phytoconstituents.

Among all the plant parts analyzed, the leaves yielded the highest amount of crude extract (2.60 g) with an extraction yield of 26.0%, suggesting that leaf tissues contain the highest concentration of methanol-soluble constituents. These may include phenolics, flavonoids, tannins, sugars, glycosides, organic acids, and other polar secondary metabolites. The leaf extract appeared dark greenish-brown and thick semi-solid, which may be due to the presence of chlorophyll derivatives along with phenolic and other extractable compounds.

The root extract yielded 1.95 g extract with 19.5% extraction efficiency, which was lower than leaves and stem. Although Hemidesmus indicus roots are medicinally important, the lower extractive value suggests that root tissues may contain comparatively less methanol-soluble matter or a greater proportion of structural and fibrous components. The root extract was dark brown and viscous, reflecting the presence of root-specific aromatic and resinous constituents.

The stem gave the lowest crude extract (1.72 g) and lowest extraction yield (17.2%), indicating that stem tissues contain the smallest number of solvent-soluble phytochemicals among the plant parts tested. The stem extract was light brown and semi-solid to sticky, suggesting lower concentration of secondary metabolites compared to leaves and root.

Overall, the extraction yield followed the order: Leaves > Roots > Stem

This trend indicates that aerial and protective tissues of H. indicus contain greater quantities of extractable constituents than supporting tissues like stem. The data also suggest that leaves and bark are promising plant materials for phytochemical extraction and further phenolic analysis.

Table 2. Total Phenolic Content and Related Parameters in Different Plant Parts of Hemidesmus indicus

Sr. No.	Plant Part	Absorbance at 765 nm	Gallic Acid Equivalent from Standard Curve (mg/mL)	Total Phenolic Content (mg GAE/g DW)	Rank	Relative Phenolic Level
1	Leaves	0.954	0.954	95.40	1	Very high
4	Roots	0.609	0.609	60.85	4	Moderate
5	Stem	0.524	0.524	52.40	5	Lower

Table 2 presents the total phenolic content (TPC) of methanolic extracts obtained from different plant parts of Hemidesmus indicus, the data clearly show that the leaves possessed the highest total phenolic content (95.40 mg GAE/g DW) and were therefore ranked first among all the plant parts studied. The corresponding absorbance value at 765 nm was also the highest (0.954), indicating strong reduction of the Folin–Ciocalteu reagent due to a high concentration of phenolic compounds. The phenolic level in leaves was categorized as very high, emphasizing that leaves are the richest source of phenolic metabolites in H. indicus. This may be attributed to the active metabolic role of leaves and their constant exposure to ultraviolet light, oxidative stress, and pathogen attack, which stimulate the biosynthesis of phenolic antioxidants.

The roots contained 60.85 mg GAE/g DW, with an absorbance of 0.609, and were classified as having a moderate phenolic level. Although H. indicus roots are highly valued medicinally, the present results indicate that they are not the richest source of total phenolics within the plant. Their therapeutic value may therefore be associated not only with phenolics but also with other classes of phytochemicals such as saponins, glycosides, triterpenoids, and volatile compounds.

The stem exhibited the lowest total phenolic content (52.40 mg GAE/g DW) and the lowest absorbance (0.524), placing it at the fifth rank. The lower phenolic concentration in stem may be due to its structural role, where more emphasis is placed on support and transport than on synthesis and storage of soluble phenolic compounds.

Table 3. Comparative Distribution of Phenolics in Different Plant Parts of Hemidesmus indicus

Sr. No.	Plant Part	Total Phenolic Content (mg GAE/g DW)	Difference from Highest Value	Percent of Maximum Phenolic Content (%)	Category of Richness	Comparative Status
1	Leaves	95.40	0.00	100.00	Richest source	Highest
4	Roots	60.85	34.55	63.78	Moderate	Lower than fruits
5	Stem	52.40	43.00	54.93	Poorer source	Lowest

Table 3 provides a comparative assessment of the distribution of phenolic compounds in the different plant parts of Hemidesmus indicus. The leaves served as the reference point because they contained the highest phenolic concentration (95.40 mg GAE/g DW), and therefore their difference from the highest value was zero and their relative phenolic contribution was taken as 100%. This confirms that leaves are the richest phenolic reservoir among all the plant parts studied.

The roots contained 60.85 mg GAE/g DW, which was 34.55 units lower than the maximum, accounting for 63.78% of the phenolic level of leaves. This demonstrates that although roots contain an appreciable amount of phenolics, their phenolic richness is considerably lower than that of aerial tissues like leaves and bark. This observation is particularly important because Hemidesmus indicus is traditionally known for its medicinal roots; however, from the standpoint of total phenolics, roots are not the richest organ.

The stem recorded the lowest phenolic content (52.40 mg GAE/g DW), showing a difference of 43.00 units from the highest value and contributing only 54.93% of the maximum phenolic level. This confirms that stem is the least suitable source for obtaining phenolic-rich extracts.

VI. DISCUSSION

The present investigation revealed clear differences in extraction yield and total phenolic content among different plant parts of Hemidesmus indicus (L.) R.Br., indicating that phenolic compounds are differentially distributed within the plant body. Such variation is consistent with the well-established concept that the accumulation of phenolic metabolites is strongly influenced by tissue type, physiological role, developmental stage, and environmental exposure (Harborne, 1998; Lattanzio et al., 2006; Ignat et al., 2011). In the present study, leaves exhibited the highest extraction yield (26.0%) and the highest total phenolic content (95.40 mg GAE/g DW), followed by bark, fruits, roots, and stem. The observed order of phenolic accumulation was:

Leaves > Roots > Stem

This pattern suggests that the aerial and protective tissues of H. indicus are richer in phenolic constituents than the supporting stem and even the traditionally used roots.

The high phenolic content observed in leaves may be attributed to their role as metabolically active organs that are continuously exposed to intense sunlight, ultraviolet radiation, oxygen, temperature fluctuations, and attack by insects and microorganisms. To counter these stresses, leaves synthesize and accumulate large quantities of phenolic compounds, including phenolic acids and flavonoids, which function as antioxidants, UV screens, feeding deterrents, and antimicrobial agents (Kähkönen et al.,

1999; Balasundram et al., 2006; Lattanzio et al., 2006; Dai & Mumper, 2010). The high phenolic concentration in leaves of H. indicus therefore reflects their biochemical adaptation to environmental stress and indicates that leaves may possess considerable antioxidant and protective potential. Similar observations of high phenolic content in leaves have been reported in several medicinal plants, where leaves often serve as the primary site of synthesis and storage of soluble phenolics (Cai et al., 2004; Nabavi et al., 2009; Swarna et al., 2013).

The bark of H. indicus showed the second highest total phenolic content (84.75 mg GAE/g DW). Bark is a protective tissue that acts as a barrier against pathogens, insects, and mechanical injury. It is commonly enriched with tannins, lignin-associated phenolics, and defense-related secondary metabolites that help in wound healing, antimicrobial protection, and structural reinforcement (Bravo, 1998; Lattanzio et al., 2006). The substantial phenolic content in bark observed in the present study suggests that bark may also be an important source of antioxidant and antimicrobial compounds. Since bark is often underexplored compared to roots, its high phenolic value in H. indicus opens possibilities for further phytochemical and pharmacological studies.

The roots of H. indicus recorded 60.85 mg GAE/g DW, which was lower than the values observed for leaves, bark, and fruits. This result is particularly interesting because the roots of Hemidesmus indicus are traditionally the most widely used medicinal part. The lower phenolic content found in roots suggests that the pharmacological importance of H. indicus roots cannot be explained solely by total phenolics and is likely due to the presence of other bioactive constituents such as saponins, triterpenes, coumarins, essential oils, sterols, glycosides, and specific aromatic compounds (Austin, 2008; George et al., 2008; Mahalingam et al., 2014). Previous pharmacological reports on H. indicus roots have demonstrated significant antioxidant, anti-inflammatory, antiulcer, hepatoprotective, and immunomodulatory activities, indicating that multiple classes of phytochemicals may act synergistically in the medicinal effects of the root (Saravanan & Nalini, 2007; Chandra Shekar et al., 2011; Das & Devaraj, 2006). Thus, while the roots remain pharmacologically valuable, the present study suggests that they are not the richest source of total phenolics within the plant.

The stem showed the lowest phenolic content (52.40 mg GAE/g DW) and the lowest extraction yield (17.2%) among all the plant parts studied. This lower value may be related to the structural role of the stem, which is primarily involved in support and transport rather than in active synthesis or storage of soluble phenolic metabolites. Stems often contain more cellulose, hemicellulose, and lignified tissues and comparatively fewer soluble phenolics than leaves or bark (Harborne, 1998; Lattanzio et al., 2006). Nevertheless, the presence of measurable phenolic content in stem indicates that it still contributes to the phytochemical profile of the plant, though to a lesser extent.

An important observation in the present study is the positive association between extraction yield and total phenolic content. Leaves, which showed the highest extractive yield, also showed the highest phenolic content, whereas stem showed the lowest values for both parameters. This parallel trend indicates that phenolic compounds constitute an important fraction of the extractable matter in Hemidesmus indicus. Similar relationships between extraction yield and total phenolic content have been reported in several medicinal plants, where tissues rich in soluble phenolic constituents often yield greater amounts of crude extract when extracted with polar solvents (Cai et al., 2004; Brighente et al., 2007; Nabavi et al., 2009). The positive correlation observed in the present work suggests that solvent-soluble phenolic metabolites contribute substantially to the total extractive value of H. indicus.

The findings of the present study are also significant from the viewpoint of sustainable medicinal plant utilization. Hemidesmus indicus is traditionally harvested mainly for its roots, and excessive root collection may adversely affect plant survival and regeneration. The present results indicate that leaves and bark contain higher phenolic content than roots, suggesting that aerial or renewable tissues may serve as alternative sources of antioxidant phenolics. Such a shift in utilization pattern may help reduce destructive harvesting and support conservation of the species. Sustainable exploitation of leaves, especially if they possess high phenolic richness and antioxidant activity, could be advantageous for herbal industries

and local medicinal use (Kala et al., 2006; Chen et al., 2016).

The comparatively high phenolic content of leaves indicates their potential for phytochemical standardization, antioxidant assays, isolation of phenolic fractions, formulation of herbal extracts, and development of natural preservatives or nutraceuticals. Since phenolics are strongly associated with free radical scavenging and redox-modulating activities, the phenolic-rich extracts of H. indicus leaves may be useful in combating oxidative stress-related disorders. Further work involving identification of individual phenolic compounds by chromatographic techniques such as HPLC, LC-MS, or GC-MS, along with antioxidant and antimicrobial bioassays, would help clarify the exact therapeutic relevance of these plant parts.

The results of this study are in agreement with the broader concept that medicinal plants often show organ-specific phytochemical distribution, and that the part traditionally used is not always the richest in every class of bioactive compound. In the case of H. indicus, roots may still remain medicinally important because of their characteristic volatile and non-volatile constituents, but the present investigation clearly demonstrates that leaves and bark are superior sources of total phenolic compounds. Therefore, selection of plant material for pharmaceutical or nutraceutical applications should be based on the specific class of bioactive compounds of interest rather than solely on traditional usage patterns.

Overall, the present study contributes to the phytochemical understanding of Hemidesmus indicus by demonstrating marked variation in total phenolic content among different plant parts and by highlighting the importance of leaves and bark as promising sources of phenolic antioxidants. These findings may serve as a useful basis for future biochemical, pharmacological, and conservation-oriented studies on this important medicinal plant.

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