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Phytochemical diversity, pharmacological potential and value addition of selected tropical medicinal plants: A comprehensive review

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Abstract

Traditional and modern pharmacopoeia have made use of medicinal plants because these plants contain a rich pool of bioactive compounds. The given review is a synthesis of the literature on the phytochemical composition, therapeutic activities, and the value-added products of a broad scale of medicinal plants. It includes qualitative phytochemical screens, gas chromatography-mass spectrometry (GC-MS) phytochemical screening of bioactive compounds and assessment of pharmacological properties, including antioxidant, antimicrobial and cytotoxic properties. The application of antioxidant properties of different plants using the DPPH assay demonstrates substantial antioxidant capacity, with reported IC₅₀ values generally ranging from <10 to >100 µg/ml, largely attributed to major phytochemical classes such as phenolics, flavonoids, alkaloids, and terpenoids. Moreover, the possibility of the development of nutraceuticals and herbal preparations of these plants is mentioned, which shows how they are used in functional foods and therapeutics. The summarised evidence proves the rich nature of medicinal plants as a renewable source of new therapeutic agonists and functional foods. This review emphasises the inseparable essence of ethnobotanical knowledge in the phytopharmacological studies and proposes further scientific investigation and the sustainable utilisation of these botanical resources to address health demands around the world. The review primarily focuses on medicinal plants reported from tropical regions, emphasising their phytochemical diversity, pharmacological validation, and value-added applications.

1. Introduction

Medicinal plants have a long history of use by people, and their utilisation underlies the foundations of indigenous health care systems in many societies and in different parts of the world. These sources of botanicals have played an indispensable role in the treatment and management of many different ailments using a diversified arsenal of bioactive compounds referred to as secondary metabolites. What distinguishes secondary metabolites of plants is their main importance in invading plants, in defence mechanisms, development, and construction against the environment (unlike primary metabolites, whose roles are directly related to growth and development). They are important biologically to human health, and they contain a wide array of pharmacological activity, encompassing antioxidant, antimicrobial, anti-inflammatory, and anticancer activities (Yadav and Agarwala, 2011). The enduring reliance on plant-based medicine is a testament to its efficacy, accessibility, and cultural significance, providing a continuous pipeline for novel drug discovery and development.

Ethnobotanical research has played a key role in reporting on traditional knowledge of medicinal plants, providing important

understanding of the traditional applications of the plant and playing a critical role in scientific verification. As an example, tribal groups, including Malayali tribes in the Yercaud hills, have maintained a great amount of knowledge regarding the use of local plants to cure different illnesses (Senthilkumar *et al.*, 2013). A systematic study of this ethnomedical information can result in new active compounds being discovered and the justification of traditional practices being achieved (Smita *et al.*, 2012). The first phase of this scientific validation is a phytochemical screening, intended to isolate and determine the different components of vegetation to evaluate their biological action, and their possible usage as medicines (Mumtaz *et al.*, 2014). Such screenings have regularly clinched upon their discoveries of organic compounds within medicinal plants that have certain physiological effects on the human body, *i.e.*, tannins, alkaloids, carbohydrates, terpenoids, steroids and flavonoids (Yadav and Agarwala, 2011), as summarised in Table 1.

The therapeutic potential of these phytochemicals is vast and well-documented. Alkaloids, for example, are recognised as among the most efficient therapeutic agents derived from plants, possessing notable analgesic and antibacterial properties (Eleazu *et al.*, 2012). Another principal group of secondary metabolites includes flavonoids, which they use as a protective system against predation by microorganisms and display the positive activity of anti-inflammatory, antibacterial, and antioxidant (Harborne, 2000; Nandagopalan *et al.*, 2016). In addition to the defence mechanisms in plants, flavonoids also provide defence against several human

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diseases, such as allergies, inflammations, free radicals, platelet aggregation, microbial infections, ulcers, hepatotoxins, viruses, and tumours. On the same note, one of the most abundant and widespread classes of plant metabolites, the phenolic compounds, is also identified to help in the prevention of chronic illnesses like cardiovascular

disease, cancer, diabetes, as well as bacterial and parasitic infections of the human body (Canini *et al.*, 2007). They have biologic characteristics of antiapoptosis, antiageing, anticarcinogen, anti-inflammatory, antiatherosclerotic, cardiovascular-protective, antiangiogenesis and cell proliferation (Han *et al.*, 2007).

Table 1: Summary of major phytochemical classes and their medicinal properties

Phytochemical class	Reported pharmacological activities	Selected plant sources
Alkaloids	Analgesic, antibacterial, therapeutic agents	<i>Punica granatum</i> , <i>Psidium guajava</i> (Wadood <i>et al.</i> , 2013)
Flavonoids	Antioxidant, anti-inflammatory, antibacterial, anticancer	<i>Lantana camara</i> , <i>Annona squamosa</i> (Pradeep <i>et al.</i> , 2014)
Sterols	Antibacterial, relationship with sex hormones	<i>Bryophyllum pinnatum</i> , <i>Tinospora cordifolia</i> (Yadav and Agarwala, 2011)
Phenolic compounds	Antioxidant, anti-inflammatory, anticarcinogenic	<i>Carica papaya</i> , <i>Foeniculum vulgare</i> (Mumtaz <i>et al.</i> , 2014)
Anthraquinones	Laxative, anticancer, antiinflammatory, antimicrobial	Reported in three medicinal plants (Khan <i>et al.</i> , 2011)
Tannins	Astringent, antioxidant, wound healing, antiulcer	<i>Annona squamosa</i> , <i>Acalypha indica</i> (Pradeep <i>et al.</i> , 2014)
Carbohydrates	Hypoglycemic, hypolipidemic, antioxidant, anti-inflammatory	<i>Calotropis procera</i> , <i>Mangifera indica</i> (Khalid <i>et al.</i> , 2018)
Cardiac glycosides	Cardiotonic, stimulant in cardiac failure	Present in most of the 25 medicinal plants (Nandagoapalan <i>et al.</i> , 2016)
Glycosides	Cardiovascular effects, blood pressure lowering	<i>Xanthium strumarium</i> , <i>Terminalia bellerica</i> (Yadav and Agarwala, 2011)
Volatile oils	Antibacterial, antimicrobial, aromatic	Present in all plants analysed (Sharma <i>et al.</i> , 2020)

Pharmacological validation of these compounds has been done by using different types of in vitro and in vivo tests. Antioxidant activity, which is one of the vital characteristics of mitigating oxidative stress, which is a decisive factor in the pathogenesis of most chronic diseases, has received significant consideration using techniques like the DPPH (2,2-diphenyl-1-picrylhydrazyl) free radical scavenging assay. The research of such plants as *Aegle marmelos* (Bael fruit) has proved that it has a wide spectrum of pharmaceutical effects, including free radical scavenging, inhibition of lipid peroxidation, and antibacterial, antiviral, antidiarrheal, and hepatoprotective properties (Baliga *et al.*, 2011). On the same note, the *Acacia nilotica* leaf extract extracted by sequential processes was observed to possess higher antioxidant potential than extracts made by the maceration process, revealing the need for emphasis on the benefits of such extraction in terms of maximising the bioactive yield (Kalaivani and Mathew, 2010).

The discovery of new technologies of analysis, such as gas chromatography-mass spectrometry (GC-MS) has made a breakthrough in the field of phytochemical studies, allowing the identification and characterisation of bioactive compounds in plant extracts in a more accurate manner. The method has been used to profile the chemical composition of different species to expose compounds possessing high therapeutic potential. As an illustration, the GC-MS analysis of *Neolamarckia cadamba* leaf extracts has helped identify a wide range of bioactive compounds that would act as antioxidants, antimicrobials, anaesthetics, antiseptics, antidiabetics, and hypocholesterolemic in nature, highlighting the phytopharma-cological relevance of the plant (Zayed *et al.*, 2014). These types of analyses are used to correlate certain compounds with the biological activity that is observed in them to give a scientific rationale to the traditional use of these plants.

In addition to these direct uses, medicinal plants have also been exploited in the production of value added products that increase their utility, monetary worth and accessibility. By processing raw plant material into products like health drinks, herbal ointments, wines, jams and sanitisers, the process will not only reduce the losses of the harvests but also increase the consumption of the compounds which are health beneficial. As an example, value-added products derived from the *Garcinia indica* (Kokum) fruit have been demonstrated to enhance the intake of this product in a variety of communities, alongside providing beneficial health effects (Sowmya *et al.*, 2019). Equally, the standardisation of a formulation of ointment of *Wrightia tinctoria* leaves showed high wound healing properties and is a safe and effective alternative to synthetic preparations (Kumar *et al.*, 2013).

To sum up, we may state that a combination of ancient knowledge and contemporary scientific studies offers a solid guideline on the exploration of the extraordinary potentials of herbal plants. This review is based on the need to bring together and expound on the phytochemical diversity, pharmacological, and value-added uses of medicinal plants in the literature. This article attempts to elucidate the importance of medicinal plants as sustainable sources of therapeutic agents and functional products through synthesising the findings of other studies, hence encouraging the need to continue the research, protection, and reasonable use of medicinal plants in global health and wellness.

The enduring reliance on plant based medicine is a testament to its efficacy, accessibility, and cultural significance, providing a continuous pipeline for novel drug discovery and development. Several medicinal plants discussed in this review possess well documented pharmaceutical relevance; for instance, *A. marmelos* exhibits antioxidant,

hepatoprotective, and antidiabetic activities, while *A. nilotica* is known for its strong free radical scavenging and antimicrobial properties. Similarly, *N.cadamba* and *W. tinctoria* contain diverse bioactive compounds with significant therapeutic potential.

2. Phytochemical analysis of medicinal plants

Phytochemical screening is a complementary action in pharmacognosy, involved in determining the existence of diverse bioactive acids within plants. This initial screening can give a clue to the possible therapeutic potential of medicinal plants and the direction of subsequent isolation and characterisation research.

2.1 Qualitative phytochemical analysis

The qualitative analysis is a preliminary chemical approach used to identify major classes of phytoconstituents in plant extracts. Although, individual phytochemical groups are discussed separately, their biological functions often overlap; therefore, similar functional attributes are described concisely to avoid redundancy while retaining pharmacological significance. Although, individual phytochemical groups are discussed separately, their biological functions often

overlap; therefore, similar functional attributes are described concisely to avoid redundancy while retaining pharmacological significance. The tests are the foundation of the knowledge about the chemical diversity and medical capacity of plants. These phytochemicals also differ extensively among plant species and depend on parameters including the part of plant used, geological studies, as well as the mode of extraction, as evidenced by the comparative analysis as shown in Table 2.

2.1.1 Alkaloids

Alkaloids are nitrogen-containing substances that are characterised by strong physiological properties. They are regarded as one of the most effective therapeutic agents among plant substances with great analgesic and antibacterial effects (Eleazu *et al.*, 2012). According to Nandagoapalan *et al.* (2016), 16 of 25 medicinal plants studied contained alkaloids, thus demonstrating the high prevalence and significance of the respective alkaloids as the causative component of medicinal properties of the respective plants. The alkaloids were already registered in the presence of *Punica granatum*, *Psidium guajava*, *Morus nigra* and *Prunus persica* (Wadood *et al.*, 2013).

Table 2: Comparative qualitative phytochemical analysis of selected medicinal plants from various studies

Plant name	Alkaloids	Flavonoids	Tannins	Saponins	Sterols	Phenolics	Glycosides	References
<i>Rosa damascena</i> (Red rose)	+	+	+	+	+	+	+	Mumtaz <i>et al.</i> , 2014
<i>Foeniculum vulgare</i> (Fennel)	+	+	+	+	+	+	+	
<i>Carica papaya</i> (Papaya)	+	+	+	-	+	+	+	
<i>Nicotiana tabacum</i> (Tobacco)	+	+	+	+	-	+	+	
<i>Cichorium intybus</i> (Chicory)	+	+	+	-	+	+	+	
<i>Trachyspermum ammi</i> (Ajwain)	+	+	+	+	+	+	+	
<i>Solanum nigrum</i> (Makao)	+	+	+	+	+	+	+	
Key	+ = Present - = Absent							

2.1.2 Flavonoids

The flavonoids constitute a broad category of polyphenolic structures with antioxidant properties and many different biological potentials. These latter metabolites also protect against predation by microbial organisms (Nandagopalan *et al.*, 2016). Harborne (2000) explicates that the flavonoids found in plants have numerous practical functions, such as anti-inflammatory effects, antibacterial effects, and others. Also expounded that it is used to prevent allergies, inflammation, free radicals, platelet aggregation, microorganisms, ulcers, hepatotoxins, viruses, and tumours. According to Pradeep *et al.* (2014), *Lantana camara*, *Annona squamosa*, *Carica papaya* and *Acalypha indica* contained flavonoids.

2.1.3 Sterols

The interaction between steroidal compounds and sex hormones makes them of special interest in pharmacy. Medicinal plants are typically known to possess curative properties due to the presence of diverse secondary metabolites, such as steroids (Arora, 2013). According to Epanand *et al.* (2007), steroids have antibacterial properties. Yadav and Agarwala (2011) had also reported the occurrence of sterols in the leaves of *Bryophyllum pinnatum*, *Ipomea aquatica*, *Oldenlandia corymbosa*, *Ricinus communis*, *Terminalia bellerica* and in the bark of *Tinospora cordifolia*.

2.1.4 Phenolic compounds

Phenolic compounds form one of the most comprehensive and the most widespread categories of plant metabolites (Singh *et al.*, 2007). These compounds are significant in the prevention of a variety of chronic illnesses such as cardiovascular disease, cancer, diabetes, bacteria and parasite infections (Canini *et al.*, 2007). Han *et al.* (2007) reported that they possessed a variety of biological functions, antiapoptosis, antiaging, anticarcinogen, antiinflammation, antiatherosclerosis, cardiovascular protection, enhanced endothelial activities, and antiangiogenesis and anticell proliferation activities. The authors found phenolic compounds in *C. papaya*, *Cichorium intybus*, *Foeniculum vulgare*, *Nicotiana tabacum*, *Rosa damascena*, *Solanum nigrum* and *Trachyspermum ammi* (Mumtaz *et al.*, 2014).

2.1.5 Anthraquinones

Anthraquinones are known to have various pharmacological properties such as laxative, anticancer, anti-inflammatory, antiarthritic, antifungal, antibacterial, antiviral, antiplatelet and neuroprotective. They also demonstrate the possibility of treating malaria and multiple sclerosis (Malik and Müller, 2016). Anthraquinones, as ingredients of medicinal plants, have a long historical record as laxatives. The anthraquinones were reported by Khan *et al.* (2011) to be present in three medicinal plants at Margalla Hills.

2.1.6 Tannins

Tannins have been recognised to have astringent properties and various biological functions. Rajurkar and Gaikwad (2012) argue that tannins have an antioxidant effect, free radical scavenger; they aid in wound recovery and are useful in peptic ulcers. Okwu and Josiah (2006) linked analgesic and anti-inflammatory effects to tannins and stated that it has an effect on the factor of astringency, which rates the quick healing of mucous membranes that are inflamed. The authors found tannins in *A. squamosa* and *A. indica* (Pradeep *et al.*, 2014).

2.1.7 Carbohydrates

Carbohydrates are considered to be one of the largest phytochemical groups, having various biological activities. Recent research indicated that carbohydrates have hypoglycemic, hypolipidemic, anticholesterolemic, antioxidant, anti-inflammatory, and detoxifying effects (Zhang *et al.*, 2018; Chen *et al.*, 2019; Ganesan and Xu, 2019). According to Momin *et al.* (2012), medicinal plants contain sugars, which serve as therapeutic agents. In their studies, Njoku and Obi (2009) stated that all the selected medicinal plants contained carbohydrates, whereas Khalid *et al.* (2018) examined selected medicinal plants in the state of Gujarat and identified carbohydrates in *Calotropis procera*, *L. camara* and *Mangifera indica*.

2.1.8 Cardiac glycosides

The stimulants of cardiac failure include cardiac glycosides that have had more than two hundred years of application (Olayinka *et al.*, 1992). The specific effect of these compounds is defined by action on the contractile forces of the cardiac muscle. According to Nandagoapalan *et al.* (2016), cardiac glycosides were found in the majority of 25 medicinal plants studied in their paper.

2.1.9 Glycosides

Glycosides are associated with cardiovascular effects and lowering blood pressure. Glycosides have the capability of reducing blood pressure (Nyarko and Addy, 1990). Aslam *et al.* (2009) defined glycosides based on the effects on contractile forces on cardiac muscle. Yadav and Agarwala (2011) reported glycosides in the leaves of *Xanthium strumarium*, *B.pinnatum*, *I. aquatica*, *O. corymbose*, *R. communis* and the seed bark of *T. cordifolia*.

2.1.10 Volatile oils

Essential oils or volatile oils are volatile aroma compounds present in concentrated hydrophobic liquids. The compounds are the source of the typical odours of plants and have important biological properties. Akthar *et al.* (2014) proposed that the impact of essential oils in plants is one of the causes of antibacterial and antimicrobial effects. According to Sharma *et al.* (2020), in Bhaktapur, the selection of medicinal plants revealed the existence of volatile oils in all the assessed plants.

3. Gas chromatography-mass spectrometry (GC-MS) analysis of bioactive compounds

The analysis of bioactive compounds involving plant extracts has become an effective method for the analysis of bioactive compounds, which is achievable by the use of GC-MS. The method is used to give comprehensive data about the chemical content of medicinal plants and in the process of matching certain compounds with their biological activity.

3.1 Bioactive compounds identified in various medicinal plants

GC-MS analysis of various herbal plants has indicated that many bioactive compounds with strong therapeutic effects and with a wide taxonomic diversity have been found in this entire taxonomic group, as extensively described in Table 3.

Table 3: Bioactive compounds identified through GC-MS analysis in various plant sources and their therapeutic activities

Plant Source	Bioactive compounds	Therapeutic activities	References
<i>Symplocos cochichinensis</i> bark	n-Hexadecanoic acid, dihydroxyacetone, maltol, picrotoxin	Antioxidant, antifungal, antimicrobial, CNS stimulant	Suwethaasri <i>et al.</i> , 2025
<i>Psydrax dicoccos</i> leaf	Dexamethasone phosphate, digitoxin, hexadecanoic acid-methyl ester, phytol	Anti-inflammatory, immunosuppressive, antiviral, anticancer, antibacterial, antioxidant	Samtani and Jusko, 2005
<i>Neolamarckia cadamba</i> leaf	Various bioactive compounds	Antioxidant, antimicrobial, anaesthetic, antiseptic, antidiabetic, hypocholesterolemic	Zayed <i>et al.</i> , 2014
<i>Rhododendron arboreum</i> leaf	Active phytoconstituents	Medical efficacy, source of bioactive compounds	Painuli <i>et al.</i> , 2016
<i>Eruca sativa</i> leaf	4-methylthiobutylisothiocyanate, 5-methylthiopentanitrile	High concentration of sulphur- and nitrogen-containing compounds	Miyazawa <i>et al.</i> , 2002
<i>Enhalus acoroides</i> seagrass	Tetratetracontane	Antioxidant, cytoprotective activity	Amudha <i>et al.</i> , 2018
<i>Cyperus alternifolius</i> leaf	12,15-octadecadiynoic acid	Anti-inflammatory property	Al-Gara <i>et al.</i> , 2019
<i>Eupatorium odoratum</i>	Neophytadiene	Antipyretic, antimicrobial, anti-inflammatory, analgesic, antioxidant	Raman <i>et al.</i> , 2012

3.1.1 *Symplo coscochichinensis* bark

The bacterial profile of the *S. cochichinensis* through the GC-MS analysis showed the existence of various bioactive compounds such

as Z-(13,14-Epoxy) tetradec-11-en-1-ol acetate, n-hexadecanoic acid, dihydroxyacetone, maltol, and picrotoxin. These are compounds with varied biological properties: n-hexadecanoic acid has antioxidant and antifungal activity, dihydroxyacetone phosphate is an antifungal

compound, maltol is a central nervous system stimulant and antidote and picrotoxin has antimicrobial activity. We find the existence of these compounds in connection with the traditional applications of this plant in the treatment of numerous conditions (Suwethasriet *et al.*, 2025).

3.1.2 *Neolamarckia cadamba* leaf

A study by Zayed *et al.* (2014) aimed to determine the phytochemical compounds in *N. cadamba* leaf extracts using GC-MS. These findings revealed that the *N. cadamba* contained different bioactive compounds, and the compounds identified had antioxidant, antimicrobial, anaesthetic, antiseptic, antidiabetic and hypocholesterolemic properties and thus recommended it as a plant with phyto-pharmaceutical significance.

3.1.3 *Rhododendron arboreum* leaf

Painuli *et al.* (2016) performed the gas chromatography mass spectrometry analysis of the leaf of *R. arboreum* with the help of the methanol extract. Active phytoconstituents with the highest and the lowest percentage of area were identified by them. The derived compounds can be utilised in medical efficacy, and the plants can be utilised in the sourcing of the compounds.

3.1.4 *Eruca sativa* leaf

Miyazawa *et al.* (2002) studied the composition of the essential oil that can be obtained in the leaves of *E. sativa* with the help of the GC-MS. The outcome revealed that the essential oil had a total of 67

volatile components that amounted to 96.52 % of the oil. Its major components were 4-methylthiobutylisothiocyanate (60.13%) and 5-methylthiopentanitrile (11.25%), and also the essential oil had a very high percentage of sulphur and nitrogen based compounds.

3.1.5 *Enhalus acoroides* seagrass

A mudha *et al.* (2018) investigated the chemical composition of *E. acoroides* seagrass extract using GC-MS analysis and identified tetratetracontane as a major constituent. This compound is reported to possess notable antioxidant and cytoprotective properties, suggesting its potential role in mitigating oxidative stress and protecting cellular integrity.

3.1.6 *Cyperus alternifolius*

Al-Gara *et al.* (2019) analyzed the phytochemical profile of *C. alternifolius* and reported the presence of 12,15-octadecadiynoic acid. The compound exhibited significant anti-inflammatory activity, thereby providing scientific support for the therapeutic relevance of this species.

3.1.7 *Eupatorium odoratum*

Raman *et al.* (2012) conducted GC-MS analysis of *E. odoratum* and identified neophytadiene as an important bioactive compound. Neophytadiene has been associated with a wide range of pharmacological activities, including antipyretic, antimicrobial, anti-inflammatory, analgesic, and antioxidant effects, underscoring the medicinal value of the plant.

Table 4: Antioxidant activity (IC₅₀ values) of selected medicinal plant extracts

Plant name	Part used	Extract type	IC ₅₀ value (µg/ml)	References
<i>Acacia nilotica</i>	Leaf	Ethanollic (Sequential)	6.5	Kalaivani and Mathew, 2010
<i>Acacia nilotica</i>	Leaf	Maceration	45.0	Prakash <i>et al.</i> , 2009
<i>Desmodium gangeticum</i>	Root	Methanolic	0.19	
<i>Eclipta alba</i>	Leaf	Methanolic	0.08	
<i>Ocimum sanctum</i>	Leaf	Aqueous/Methanolic	0.05	
<i>Piper longum</i>	-	-	0.10	
<i>Solanum nigrum</i>	-	-	0.12	
<i>Amaranthus caudatus</i>	-	-	0.14	
Ascorbic acid (Standard)	-	-	Lower than all crude extracts	Various studies

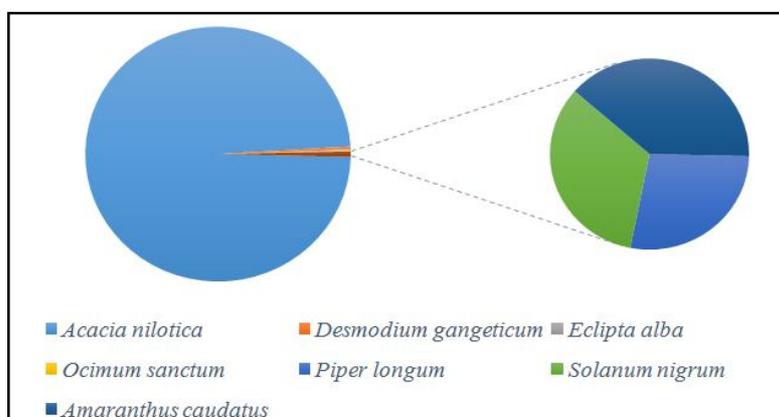


Figure 1: Comparative antioxidant potential of various medicinal plant extracts measured by DPPH assay. Lower inhibitory concentration₅₀ (LIC₅₀) indicates higher antioxidant activity.

4. Antioxidant activities of medicinal plants

Antioxidant activity is one of the greatest pharmacological effects of medicinal plants since oxidative stress has been reported to be a cause of the pathogenesis of many chronic diseases, such as cancer, heart disease, diabetes and neurodegenerative diseases. Plants contain phytochemical constituents that are good sources of antioxidants that have free radical scavenging properties (Umesh, 2015).

4.1 Evaluation of antioxidant potential

Medicinal plants with respect to their antioxidant capabilities have been widely tested using different *in vitro* models, with the DPPH (2,2-diphenyl-1-picrylhydrazyl) free radical scavenging being one of the most widely used tests. This test is used to estimate the capacity of plant extracts to donate hydrogen atoms/electrons to stabilise the DPPH radical, and the results are normally presented as inhibitory concentration (IC_{50}) values, representing the concentration required to scavenge 50% of DPPH free radicals, as summarised in Table 4 and Figure 1.

Kumar *et al.* (2008) tested the antioxidant assay of the selected medicinal plants and found the highest resistance to the lipid peroxidation activity in *Albizia amara* (96%), *Cassia fistula* (89%) and *Cassia auriculata* (89%). The findings showed that the antioxidant value of *A. amara* can be used to prepare drugs.

In a study comparing two methods of extracting *A. nilotica* leaves, Kalaivani and Mathew (2010) found that sequential extraction was more successful than the maceration method. The ethanolic extract of the leaf contained an IC_{50} of 6.5 $\mu\text{g/ml}$, and the maceration technique contained an IC_{50} of 45 $\mu\text{g/ml}$. Sequential extraction of *A. nilotica* leaf demonstrated the existence of potential antioxidant properties that can be applied in pharmaceutical industries and food preparation.

Baliga *et al.* (2011) have provided a comprehensive review of the therapeutic effects of *A. marmelos* (Bael fruit) and presented a wide range of activities, including free radical scavenging, antioxidant, lipid peroxidation, antibacterial, antiviral, antidiarrheal, gastroprotective, antiulcerative colitis, hepatoprotective, antidiabetic, cardioprotective, and radioprotective activities.

In vitro experiments that aimed to perform antioxidant studies of *Hypochoeris radicata* root and leaf aqueous and alcoholic extracts using standard procedures such as the DPPH, NO, ABTS radical scavenging capacity, and reducing power, β -carotene, and antihemolytic activity assays were carried out by Senguttuvan *et al.* (2014). They concluded that the species demonstrated good scavenging of free radicals and had antioxidant potential.

Umaiyambigai *et al.* (2017) identified the antioxidant activity of various extracts of *Psidium guajava* leaves *in vitro* by the DPPH technique. The findings indicated that the phenol and flavonoid content in the methanolic extracts of *P. guajava* was the highest, meaning that it may be a good source of natural antioxidants that find application in the development of new bioactive compounds.

Motalleb (2005) established that free radical scavenging activity increases with concentration, indicating higher antioxidant property. This finding was in accordance with the report of Ansari and Chandel (2019), who indicated lower IC_{50} values in the standard compared to the crude methanolic extract of *Gymnosporia montana*.

Prakash *et al.* (2009) evaluated six medicinal plants using ascorbic acid as a standard and found varying IC_{50} values, with *Desmodium gangeticum* (0.19) showing the highest antioxidant property, followed by *Eclipta alba* (0.08), *Ocimum sanctum* (0.05), *Piper longum* (0.1), *S. nigrum* (0.12) and *Amaranthus caudatus* (0.14).

The free radical scavenging activity was marked in the crude methanolic extract of the rhizome of *Drynaria quercifolia*, which eventually corroborated the capacity of medicinal plants as antioxidants. The antioxidant activity of medicinal plants varies significantly depending on the plant part used and the extraction method.

5. Bioassay screening of medicinal plants

The screening of bioassays gives important data on the biological activities and possible toxicity of medicinal plant extracts. These tests are essential initial tests in the assessment of the safety and efficacy of plant-based therapeutics.

5.1 Brine shrimp lethality assay

Another significant biotoxic compound lethality assay is the brine shrimp lethality assay, which is used to screen the crude extracts (Sarah *et al.*, 2017). The larvae of *Artemia salina* (brine shrimp) are used in this assay to determine the toxicity, with the results measured in LC_{100} (the concentration that induces 50% mortality of the brine shrimp nauplii).

Sharmin *et al.* (2018) found that the mortality increased with high-level concentration of methanolic leaf extract of *Aporosa wallichii* in brine shrimp. On the same note, Asoso *et al.* (2019) have indicated that there was a progressive rise in mortality with increasing doses of *C. procera* leaf extract.

According to Ved *et al.* (2010), a majority of the plant extracts were reported to cause full mortality to brine shrimp nauplii at the concentration of 1000 $\mu\text{g/ml}$ 24 h post exposure. Waghulde *et al.* (2019) also indicated the same, observing that all the brine shrimps died without any indication of survival at the concentration of 1000 $\mu\text{g/ml}$ after 24 h.

Toxicity in the brine shrimp lethality assay was expressed as lethal concentration (LC_{50}), which represents the concentration of the test extract, expressed in micrograms per millilitre ($\mu\text{g/ml}$), required to cause 50% mortality of *A. salina* nauplii after 24 h of exposure. Based on LC_{50} values, the degree of toxicity was classified into four categories: highly toxic ($LC_{50} < 10 \mu\text{g/ml}$), moderately toxic ($LC_{50} = 10-100 \mu\text{g/ml}$), less toxic ($LC_{50} = 100-1000 \mu\text{g/ml}$) and non-toxic or inactive ($LC_{50} > 1000 \mu\text{g/ml}$), following the classification proposed by Tanamatayarat (2016) (Table 5) (Figure 2).

6. Value-added products from medicinal plants

Value addition of medicinal plants is an important strategy for enhancing their economic value, improving utilization, and reducing post-harvest losses. The development of functional foods, nutraceuticals, and herbal formulations demonstrates the translational potential of medicinal plants from traditional knowledge to market oriented applications. These products include functional foods and nutraceuticals, herbal formulations and personal care items, with some of them included in Table 6.

Table 5: Toxicity classification based on brine shrimp lethality assay (Tanamatayarat, 2016)

Toxicity category	LC ₅₀ Value (µg/ml)	Interpretation
Highly toxic	< 10	Indicates the presence of potent cytotoxic compounds, which require careful toxicological evaluation.
Moderately toxic	10 - 100	Suggests significant bioactivity, potential for drug development with safety profiling.
Less toxic	100 - 1000	Indicates a safer profile, suitable for further pharmacological studies.
Non-toxic/Inactive	> 1000	Considered non-toxic in this assay, a high safety margin is expected.

LC₅₀: Lethal concentration required to cause 50% mortality of brine shrimp nauplii

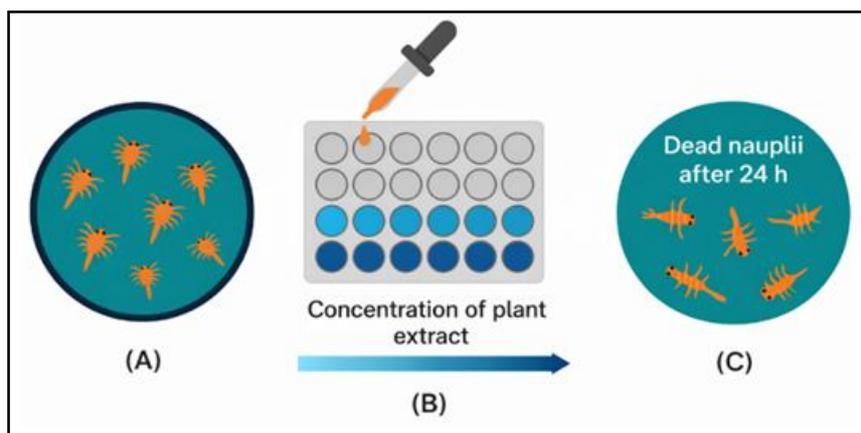


Figure 2: Experimental setup and observation for the brine shrimp lethality bioassay.

6.1 Functional foods and nutraceuticals

Sunil *et al.* (2012) examined the antioxidant, antidiabetic and antilipidemic properties of *S. cochichinensis* bark methanolic extract (SCBe) in streptozotocin (STZ)-induced diabetic rats. *In vitro* studies on SCBe showed a lot of DPPH (IC₅₀ 820.21 µg/ml), hydroxyl (IC₅₀ 884.19 µg/ml) and nitric oxide (IC₅₀ 860.21 µg/ml) radical scavenging, and a great deal of reducing power. The 28-day administration of SCBe (250 and 500 mg/kg) demonstrated antilipidemic properties in diabetic rats, which was revealed by a reduction in serum TC, TG, and LDL-C and an increase in serum HDL-C. SCBe was found to be similar to a standard diabetes drug, glibenclamide and therefore could be used in the management of diabetes mellitus.

Ulikkashi *et al.* (2017) introduced the value-added products based on the fruit of bael (*A. marmelos*), which has great nutritional and medicinal values. During the year, bael juice, jam and toffee were developed to ensure that the market share is not lost. Sensory testing indicated that Bael juice mixed with jaggery and lime was positive over that of sugar and lime, jaggery and sugar and control. Bael jam and toffee received high acceptance with high sensory ratings and products were all highly rated in terms of consumer rating.

In their study, Patil *et al.* (2012) used Jamun (*Syzygium cumini*) fruit in the production of wine at different levels of treatment. The alcohol content of wine was between 6.62 and 10.25% depending on the concentration of the total soluble sugars (7.88 to 10.53%) and the yeast concentration [T₁ (5%), T₂ (10%), T₃ (15%) and T₄ (20%)]. Out of the four treatments, T₂ (10% yeast) scored the best on flavour, taste and astringent properties and the amount of ingredients and duration taken was standardised.

Sowmya *et al.* (2019) have mentioned the production of various value-added products made using the fruit of *G. indica*. It came up with five standardised products, including kokum sambar mix, kokum spice candy, kokum sauce, kokum pickle, and kokum popsicles, which all have good health characteristics. The sensory determination showed that kokum popsicles ranked highest. The findings showed that, addition of values to kokum fruits would make them more consumed by different communities and less would be lost after harvesting this underutilised fruit.

6.2 Herbal formulations

Kumar *et al.* (2013) undertook a study to evaluate the reasoning for utilising the leaves of *W. tinctoria* traditionally. They tested the efficacy of a wound healing ointment against a standard and the findings presented the effectiveness of *W. tinctoria* ointment as a therapy and a safe alternative to using synthetic drug ointments (Figure 3). The experiment performed by Bagade *et al.* (2021) with the extract of *Argemone mexicana* on a gel base enabled creating a high-antibacterial handwash whose use minimised itching, dryness, irritation, and dermatitis. Kannahi and Dhivya (2014) made a health drink with *Centella asiatica* and *Solanum indicum* and had it tested in terms of phytochemical analysis and antioxidant assay, which found the health drink to be more active than the individual medicinal plants. Vennila (2022) added tamarind seed kiln fruit and vegetable-based products such as tomato ketchup, instant vegetable soup mix, pineapple squash, pineapple jam, as well as guava jelly. Taste tests indicated the best incorporation percentages of tamarind seed kernel powder with all products of products. Miyazawa *et al.* (2002) prepared the components of the essential oil of *E. sativa* using leaves through GC-MS. The findings revealed that the essential oil had 67 volatile compounds, which formed 96.52% of the oil. The major

components have been 4-methylthiobutylisothiocyanate (60.13) and 5-methylthiopentanitrile (11.25), and the essence oil possessed a

high content of sulphur and nitrogen-containing substances, meaning that it can be applied in many ways.

Table 6: Examples of value-added products developed from medicinal plants

Product category	Plant source	Value added products	Key findings	References
Health drink/ Beverage	<i>Syzygium cumini</i> (Jamun)	Wine	T ₂ treatment (10% yeast) gave the best sensory scores, with alcohol content 6.62 -10.25%.	Patil <i>et al.</i> , 2012
	<i>Centella asiatica</i> , <i>Solanum indicum</i>	Health drink	Phytochemical and antioxidant activity were higher in the drink than in raw plants.	Kannahi and Dhivya, 2014
Functional foods	<i>A. marmelos</i> (Bael)	Juice, Jam, Toffee	Bael juice with jaggery and lime was most acceptable. Jam and toffee had high sensory scores.	Ulikkashi <i>et al.</i> , 2017
	<i>Garcinia indica</i> (Kokum)	Sambar mix, Candy, Sauce, Pickle, Popsicles	Kokum popsicles had the highest sensory acceptance score.	Sowmya <i>et al.</i> , 2019
Herbal formulation	<i>Wrightia tinctoria</i>	Ointment	Standardised ointment showed significant wound healing efficacy.	Kumar <i>et al.</i> , 2013
	<i>Argemone mexicana</i>	Herbal handwash (Gel)	Showed high antibacterial activity and reduced skin irritation.	Bagade <i>et al.</i> , 2021
Food additive	Tamarind seed kernel	Powder incorporated into ketchup, soup mix, squash, jam, jelly	Optimal incorporation level achieved with good organoleptic acceptance.	Vennila, 2022



Figure 3: Examples of value-added products developed from medicinal plants.

7. Conclusion

This review consolidates evidence on the phytochemical diversity, pharmacological activities, and value-added applications of medicinal plants, highlighting their importance as sustainable sources of therapeutic agents and functional products. The presence of diverse bioactive compounds such as alkaloids, flavonoids, phenolics, and glycosides underpins their antioxidant, antimicrobial, and cytotoxic properties. Advances in analytical techniques, particularly GC-MS, have strengthened the correlation between phytochemical composition and biological activity. Furthermore, the development of value-added products enhances both economic potential and sustainable utilization. Future research should prioritize compound

isolation, mechanism-based studies, clinical validation, and conservation-oriented utilization strategies.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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