Phytochemical Profile and Antimicrobial Effects of Different Medicinal Plant: Current Knowledge and Future Perspectives

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Abstract: The application of medicinal plants for combating various human ailments, as a food fortificant and additive have been adapted from ancient routine custom. Currently, developing countries use plants as a major source of primary health care. Besides, the emerging drug resistant pathogenic microbes encourage the utilization of medicinal plants as preeminent alternative sources of new bioactive substances. Extensive research findings have been reported in the last three decades. But methods to investigate the phytoconstituent and their biological effects are limited. This review contains brief explanations about the selection of medicinal plants, procedure for obtaining the crude as well as essential oil extracts, phytochemical screening, and in-vitro evaluation of antimicrobial activity. Furthermore, the antimicrobial activity of medicinal plant extracts reported from their respective solvent fractionated and non-fractionated in-vitro analysis has also been described in the present paper. The bioactive substances from medicinal plant along with chemical structure and biological effects are highlighted in the content.

Keywords: Antimicrobials, bioactive-compounds, medicinal plants, pathogens, phytochemicals, Hypericum perforatum.

1. INTRODUCTION

Medicinal plants are a source of natural products which have significant role in the treatment of various complications in human health [1, 2]. Understanding of existing phytochemical compounds and pharmacological properties and their structural composition are important in the preparation of medicine and its application [3, 4]. At the moment, the demand for medicinal plants for the isolation of natural bioactive compounds has increased rapidly [5, 6]. For instance, Hypericum perforatum is known as the world’s leading herbal plant due to its antiviral, anti-bacterial, anti-fungal, anti-cancer, anti-inflammatory, anti-oxidant and several other roles [7]. The presence of phytochemicals such as flavonoids, xanthones, acyl phloroglucinols, and naphthodianthrones contributes to the potency popularity [8]. Similarly, Moringa oleifera phytochemical constituents such as gallic acid, catechol-type tannins, alkaloids, saponins, and flavonoids contribute mainly to combating drug resistant microbes, antioxidants, anti-inflammatory, anti-diabetic and lowering of cholesterol level and blood pressure [9-11].
In general, the presence of phytochemicals (secondary metabolites) in plants plays a crucial role in combating various ailments of human, animals, and plants [12, 13]. Currently, the development of drug resistance, particularly by microorganisms, has been growing rapidly [14-16]. Researchers are shifting their attention towards medicinal plants to exploit new valuable bioactive compounds [17-19]. For instance, various plant extracts obtained via decoction, maceration, infusions and other forms have been confirmed for the presence of secondary metabolites which contribute to antimicrobial activities [20, 21]. Microbes such as MRSA (methicillin-resistant *Staphylococcus aureus*), *Pseudomonas aeruginosa* and *Listeria monocytogenes* are the common drug resistant and prevalent foodborne pathogens [16, 22-24]. Plant-derived substances contribute as antimicrobial agents to treat most of the virulent microbes and also used as an alternative treatment approach for drug resistant pathogens [25, 26]. Plant extracts from medicinal plant such as *Senna alata* and *Kaempferia pandurata* have been reported to be antimicrobial against *S. aureus* [27], *Camellia sinensis* against *L. monocytogenes* [28], *Anogeissus schimperi* and *Anacardium occidentale* against *P. aeruginosa* [29]. Apart from antibacterial activities, plant extracts have also displayed a multitude of properties to combat various ailments. The wide spectrum of remedial properties is because of the constituents of myriad phytochemicals [30]. Understanding of phytochemical constituents, pharmacological activities, techniques of extraction, isolation, purification and structural elucidation of bioactive compounds is crucial in the development of potent drugs [31]. The present review paper describes the identification of biologically relevant plants, extraction procedure, techniques of maintaining plant extracts and antimicrobial activity of plant extract as well as bioactive compounds.

### 2. SELECTION OF PLANT MATERIALS

Careful observation of medicinal plant used in folkloric system in a given ethnic group is crucial. Uses of ethnomedical ethnobotany principles are extremely important to collect information such as parts of the plant used, methods of preparation, dosage, and other related properties [32]. Most of the research reports showed that plant material used for a particular study was prioritized through the ethnomedical survey; accordingly, the knowledge of healers, community informants’ attitude, and biological properties of the plants are considered for investigating the active phytochemical constituents [33-35]. After selection of suitable medicinal plants, all its respective traditional applications, parts which are collected with appropriate designations are transported to the laboratory for further determination of its biological activities [36]. Moreover, references of voucher specimens should be placed in the herbarium [37, 38]. Generally, depending on the targets of bioactive type to be screened, there are numerous preconditioned techniques available. For instance, if the target substances are volatile components, the fresh plant sample is preferable [39, 40], otherwise shade dried and powdered materials are used for both target and non-target screening of active substances [41, 42].

### 3. EXTRACTION OF CRUD COMPONENTS OF PLANT

In the process of exploration of new biologically active medicinal plant constituents, there are different methods. Different parts of plant materials (root, stem, leaves, flower, and seeds) soaked in different solvents based on the polarity difference such as ethanol, acetone, methanol, water, chloroform, and hexane [43-47]. Some of the steps and techniques which are frequently used for the processing of plant material during the extraction includes the maceration [48], percolation [49], soaking [50] and Soxhlet extraction [51]. After extraction, the filtrated extracts which are concentrated and dried with the help of the rotary evaporator at reduced pressure are needed to calculate the percentage of extracts yield [52, 53]. Storage of the collected, dried extracts should be placed in the refrigerator for further tests. Several distinct approaches for the extraction of phytochemical constituents and other bioactive components have been reported earlier [54-57]. Extracts obtained via various methods must undergo chromatographic purification for the isolation of pure compounds. Sequential fractionation of compound using various polarity index solvents is required to obtain pure compounds [58, 59]. The pure compound is separated and evaluated for in-vitro and in-vivo tests to obtain information on the toxicity effects and biological assays [60]. The microorganisms, insects, molluscs, cell culture, and mammals are used for the evaluation of biological properties of
pure compound [32, 61]. Moreover, spectroscopic analysis of pure compounds through Infrared (IR), Nuclear Magnetic Resonance (NMR) and UV-visible-spectroscopy is important to determine the chemical structure [62-64]. Complete identification of the bioactive compound helps in the partial and total chemical synthesis of relevant pharmacological drugs. Fig. (1) shows plant extraction steps and processes for the screening of phytocistituent and bioassay activities.

4. EXTRACTION OF ESSENTIAL OILS

Essential oil can be extracted by various techniques such superficial carbon dioxide based extraction [65] and hydrodistillation method [66]. Commonly, hydrodistillation technique (without the use of organic solvents) has been used in the previous studies [56, 67, 68]. The techniques are conducted through the addition of water to the calculated amount of fresh plant material and vaporized until layers of aqueous and essential oils are obtained [69, 70]. Clevenger apparatus is frequently used to conduct the hydrodistillation process. The continuous extraction of fresh plant parts for 6 hours is required in order to get enough volume of oil. Essential oils obtained through the hydrodistillation process should be dried by using anhydrous sodium sulfate which removes the aqueous mixture [71]. The pure oil can be stored in a refrigerator at a low temperature until it is required for further biological activity tests.

5. SCREENING OF PHYTOCHEMICALS

Qualitative screening of secondary metabolites such as alkaloids, phenols, tannins, steroids, cardiac glycosides, flavonoids, diterpenes, and saponins has been done from medicinal plants [72-75]. The screening of all major classes of phytochemicals shows the remedial value of plants in various aspects. Qualitative phytochemical analysis mostly includes tests for alkaloids (Mayer’s test), phenols (ferric chloride test), flavonoids (alkaline reagent test), glycosides (Borntrager’s test), diterpenes (copper acetate test), tannin (gelatin test) and sterols (Salkowski’s test) [76-78]. Besides, identification of the major classes of phytochemicals through a detailed constituent analysis is done via Thin Layer Chromatography (TLC) [79], column chromatography [80], High-Performance Liquid Chromatography (HPLC) [81] And Gas Chromatography-Mass Spectroscopy (GC-MS) [82]. The evaluations of each plant-derived constituent provided detailed information of the exact biological and chemical properties. Further structural elucidation of the active constituents of a compound via Fourier Transform Ion Cyclotron Resonance (FT-ICR) was shown to be an effective technique in plant metabolomics [83]. Moreover, the use of 2D (HMBC, NOESY, COS, and HSQC) and 1D (1H and 13C) NMR spectrophotometric method has been identified as the most suitable for structural elucidation of an isolated pure compound [84].
6. EVALUATION OF ANTIMICROBIAL ACTIVITIES

For the evaluation of antimicrobial activities of medicinal plant extracts, standard microbial strains [85] and clinical isolates [86] have been used in many studies. Various methods of antimicrobial evaluation tests are available such as agar disk diffusion, agar well diffusion assay, streak plate, pour plate, and broth dilution method [31, 87, 88]. Microbial culture media dispensed in the petri plates, test tubes and polyethylene titer wells, depending on the consistency and types of agar. 6 mm diameter of Whatman filter paper disc or agar six wells filled with a measured amount of extracts and the culture should be inoculated according to the McFarland standard. After 24 hours’ incubation at 37°C, zones of microbial inhibition in diameter could be measured. Whereas in broth dilution assay, the spectrophotometer based measurement of optical density and direct observation of turbidity showed the percentage of inhibition [89].

7. PLANT-DERIVED BIOACTIVE COMPOUNDS

Conventionally, communities all over the globe have been using medicinal plants as a primary healthcare system, particularly in Africa and Asia [90]. The practice allows the scientific community to investigate the active components of the medicinal plants in relation with their respective cultural circumstances. The science of ethnopharmacology plays a crucial role in the identification and innovation of natural bioactive compounds [91]. The invention of better scientific methods, preservation of potential medicinal plants, identification of chemical constituents, standardization of the bioactive components and evaluation of biological tests are grouped under the field [92-94]. Many plant-derived compounds have been investigated due to the presence of specific chemical and biological properties. With the emergence of multi-drug resistant pathogenic organisms, the search for an alternative potential bioactive substance is under progress. Currently, the increase of drug resistance by microbes is a social issue [95, 96]. Consequently, the pharmaceutical and scientific communities are trying to discover alternative biologically active compounds. These compounds are crucial in destabilization of the cytoplasm, cell membrane, enzyme activity and overall metabolic activities of the pathogenic microbes [97]. Recently, scientific reports showed that plant-derived compounds are vital to combat various human ailments. Particularly, plant families belonging to Cuspressaceae, Fabaceae, Dracenaceae, Palmaceae, Euphorbiaceae, Anacardiaceae, Burseraceae, Pinaceae, and Apiaceae are the most commonly used as sources of antimicrobial bioactive compounds [98, 99]. Several other reports showed that essential oils, crude extracts and fractionated compounds from plant materials are also used as antibacterial, antifungal, anticancer and antiprotozoal agents [100-102]. Table 1 shows some medicinal plants as sources of potential bioactive compounds. The selected bioactive compounds with their chemical structure as well as respective biological effects have been mentioned in Table 1.

8. ROLE OF PHYTOCHEMICALS IN ANTIMICROBIAL ACTIVITIES

The antimicrobial properties of medicinal plants vary depending upon the type and presence of phytochemical constituents [103, 104]. There are myriad phytochemical constituents in various parts of the plants. For instance, more frequently available classes of phytochemicals are alkaloids, tannins, saponins, flavonoids, terpenoid, steroids and glycosides [105, 106]. All of the phytochemicals are sometimes referred to as secondary metabolites which contribute to antibacterial and antifungal properties as shown in Table 2. Moreover, plant phytochemicals also serve as antioxidant, antiulcer, antiviral, anti-diabetic, anti-inflammatory and anticancer agents [107, 108]. Huge amounts of medicinal plants have been extracted and evaluated for in-vitro antibacterial and several other properties. Several results showed that the Gram-positive bacteria are more sensitive to various classes of phytochemicals, due to the presence of single layer cell wall, whereas, the Gram-negative bacteria possess double membrane which makes them more resistant against plant extracts [109-111]. Overall, in the determination of the phytochemicals and antimicrobial efficacy, various factors should be considered. The parts of plants, methods of extraction, and properties of solvent used and morphological nature of the microbes are some of the factors [112, 113]. The selection of solvents for the extraction of particular plant material is crucial. Correlating the level of the polarity index of the solvent with the target plant material to be extracted is a key process in screening for potential phytoconstituent bioactive
Table 1. Potent plant compounds with respective biological importance.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Chemical Structure</th>
<th>Name of Active Compound</th>
<th>Type of Plant Extracts</th>
<th>Biological Importance</th>
<th>Refs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td><img src="image" alt="Chemical Structure" /></td>
<td>Quercetin</td>
<td><em>Miconia albicans</em> (<em>Sw.</em>) methanol extract and n-butanol fractionation</td>
<td>Antioxidant and other promising biological activities</td>
<td>[116]</td>
</tr>
<tr>
<td>2.</td>
<td><img src="image" alt="Chemical Structure" /></td>
<td>20-epi-dasycarpidone</td>
<td>Ethanol extract of <em>Aspidospera ulei</em></td>
<td>Antiplasmodial properties</td>
<td>[117]</td>
</tr>
<tr>
<td>3.</td>
<td><img src="image" alt="Chemical Structure" /></td>
<td>Alizexol A (Aliso-F-Acetate)</td>
<td><em>Alisma orientale</em> ethanol extract and butanol fractionation</td>
<td>Antiviral (Hepatitis B)</td>
<td>[118, 119]</td>
</tr>
<tr>
<td>4.</td>
<td><img src="image" alt="Chemical Structure" /></td>
<td>Aloesin</td>
<td><em>Aloe trigonantha</em> methanol extract and ethyl acetate and methanol fractionation</td>
<td>Antibacterial and antifungal activity</td>
<td>[120]</td>
</tr>
<tr>
<td>5.</td>
<td><img src="image" alt="Chemical Structure" /></td>
<td>Camphor</td>
<td>Steam distilled and acetone extract of <em>Euphorbia golondrina</em></td>
<td>Antibacterial, antifungal, and antioxidant properties</td>
<td>[121]</td>
</tr>
<tr>
<td>6.</td>
<td><img src="image" alt="Chemical Structure" /></td>
<td>Kaempferol-3-O-rutinoside</td>
<td>Methanolic extracts of <em>Calotropis procera</em></td>
<td>Antimicrobial activities</td>
<td>[122]</td>
</tr>
<tr>
<td>S. No.</td>
<td>Chemical Structure</td>
<td>Name of Active Compound</td>
<td>Type of Plant Extracts</td>
<td>Biological Importance</td>
<td>Refs.</td>
</tr>
<tr>
<td>--------</td>
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<td>------------------------</td>
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</tr>
<tr>
<td>7.</td>
<td><img src="https://example.com/isogarcinol%E7%BB%93%E6%9E%84%E5%9B%BE" alt="Isogarcinol" /></td>
<td>Isogarcinol</td>
<td>Leaves extracts of <em>Hypericum lanceolatum</em> n-hexane and ethyl acetate fractionation</td>
<td>Antibacterial against <em>Shigella flexneri</em>, <em>Klebsiella pneumoniae</em> and <em>Salmonella typhi</em></td>
<td>[123]</td>
</tr>
<tr>
<td>8.</td>
<td><img src="https://example.com/taxifolin%E7%BB%93%E6%9E%84%E5%9B%BE" alt="Taxifolin" /></td>
<td>Taxifolin</td>
<td><em>Eucalyptus camaldulensis</em> ethyl acetate extract and n-hexane and ethyl acetate fractionation</td>
<td>Identified as antimicrobial activities and inhibition of Schistosomical properties</td>
<td>[124]</td>
</tr>
<tr>
<td>9.</td>
<td>![1,2,3,4,5,6-hexa-O-acetyl galactitol](<a href="https://example.com/1,2,3,4,5,6-hexa-O-acetyl">https://example.com/1,2,3,4,5,6-hexa-O-acetyl</a> galactitol结构图)</td>
<td>1,2,3,4,5,6-hexa-O-acetyl galactitol</td>
<td>Water extracts of <em>Trachyspermum ammi</em> and fractionated by phenol and sulphuric acid</td>
<td>Essential for antimicrobial effects such as <em>Staphylococcus aureus</em>, <em>Bacillus subtilis</em>, <em>Escherichia coli</em> and <em>Pseudomonas aeruginosa</em></td>
<td>[125]</td>
</tr>
<tr>
<td>10.</td>
<td><img src="https://example.com/%CE%B2-sitosterol%E7%BB%93%E6%9E%84%E5%9B%BE" alt="β-sitosterol" /></td>
<td>β-sitosterol</td>
<td>Chloroform extracts of seed of <em>Malva parviflora</em> and fractionated by petroleum and chloroform</td>
<td>Showed potential antibacterial activities particularly <em>S. aureus</em> and <em>E. coli</em></td>
<td>[126]</td>
</tr>
<tr>
<td>11.</td>
<td>![Ellagic acid](<a href="https://example.com/ellagic">https://example.com/ellagic</a> acid结构图)</td>
<td>Ellagic acid</td>
<td>Ethanol extracts of <em>Dissotis senegambiensis</em>, fractionated by ethyl acetate and n-butanol</td>
<td>Showed promising antibacterial and anti-fungal properties</td>
<td>[127]</td>
</tr>
<tr>
<td>12.</td>
<td>![3,11-dihydroxylacyl-12-ene-30-oic acid](<a href="https://example.com/3,11-dihydroxylacyl-12-ene-30-oic">https://example.com/3,11-dihydroxylacyl-12-ene-30-oic</a> acid结构图)</td>
<td>3,11-dihydroxyolean-12-ene-30-oic acid</td>
<td>The leaves extracts of <em>Maytenus undata</em> and methanol and chloroform fractionation</td>
<td>The first reported compound which has good antibacterial against <em>E.coli</em> and antifungal activity</td>
<td>[128]</td>
</tr>
</tbody>
</table>

(Table 1) Contd....
<table>
<thead>
<tr>
<th>S. No.</th>
<th>Chemical Structure</th>
<th>Name of Active Compound</th>
<th>Type of Plant Extracts</th>
<th>Biological Importance</th>
<th>Refs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.</td>
<td><img src="image1" alt="Chemical Structure" /></td>
<td>5’-Methoxyhydnocarpin</td>
<td>Berberine fremontii hexane extract and fractionations by chloroform and methanol</td>
<td>Inhibit the multi drug resistance pumps of Staphylococcus aureus</td>
<td>[129]</td>
</tr>
<tr>
<td>14.</td>
<td><img src="image2" alt="Chemical Structure" /></td>
<td>7-Amino-4-methylcoumarin</td>
<td>Ginkgo biloba endophytic Xylaria sp.</td>
<td>Wide range of antibacterial and antifungal properties</td>
<td>[130]</td>
</tr>
</tbody>
</table>

Table 2. List of screened phytochemicals and their antimicrobial properties.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Name of Plants</th>
<th>Parts of Plant and Extraction Solvent</th>
<th>Antimicrobial Properties</th>
<th>Phytochemicals</th>
<th>Refs.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dissotis senegambiensis</td>
<td>Whole plant with ethyl alcohol and ethyl acetate</td>
<td>S. aureus ATCC25923, Cryptococcus neoformans H99, Candida albican 10231, Candida tropicalis PK233</td>
<td>ND D D D D D D</td>
<td>[127]</td>
</tr>
<tr>
<td>2.</td>
<td>Pleuroxpermum amabile</td>
<td>Aerial part with hexane and dichloromethane</td>
<td>S. aureus, MRSA, E. coli, B. subtilis and S. epidermidis</td>
<td>D ND ND ND ND NT NT</td>
<td>[34]</td>
</tr>
<tr>
<td>3.</td>
<td>Polyscias fulva</td>
<td>Stem bark dichloromethane-methanol (1:1 v/v)</td>
<td>C. albicans ATCC1663 Microsporum ferrugineum</td>
<td>NT NT D NT D NT NT</td>
<td>[131]</td>
</tr>
<tr>
<td>4.</td>
<td>Elaeophorbia drupifera</td>
<td>Leave with methanol</td>
<td>Enterobacter aerogenes ATCC13048, P. aeruginosa PAO1, E. coli ATCC8739</td>
<td>NT NT NT NT D D NT</td>
<td>[132]</td>
</tr>
<tr>
<td>5.</td>
<td>Maytenus undata</td>
<td>Leave with hexane</td>
<td>C. albicans, C. neoformans, E. faecalis, S. aureus, E. coli, P. aeruginosa</td>
<td>NT NT NT NT D NT NT</td>
<td>[128]</td>
</tr>
<tr>
<td>6.</td>
<td>Bauhinia kockiana</td>
<td>Flower with ethyl acetate and methanol</td>
<td>MRSA ATCC 33591 MRSA Clinical Isolate</td>
<td>NT D NT D NT NT NT</td>
<td>[133]</td>
</tr>
<tr>
<td>7.</td>
<td>Morella serata</td>
<td>Root with water, methanol, ethanol and acetone</td>
<td>Bacillus pumilus ATCC14884 Aeromonas hydrophila</td>
<td>ND D D D D D</td>
<td>[134]</td>
</tr>
</tbody>
</table>

(Table 2) Contd....
<table>
<thead>
<tr>
<th>S. No.</th>
<th>Name of Plants</th>
<th>Parts of Plant and Extraction Solvent</th>
<th>Antimicrobial Properties</th>
<th>Phytochemicals</th>
<th>Refs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.</td>
<td><em>Quercus dilatata</em></td>
<td>Whole plant methanol extract</td>
<td><em>S. aureus</em> <em>B. subtilis</em> <em>E. coli</em> Aspergillus niger Aspergillus fumigatus Aspergillus flavus</td>
<td>ND ND D ND ND NT ND</td>
<td>[136]</td>
</tr>
<tr>
<td>10.</td>
<td><em>Trichilia roka</em></td>
<td>Leave with petroleum ether</td>
<td><em>S. pyogen, E. coli Neisseria gonorrhoeae</em></td>
<td>D D ND D NT NT D</td>
<td>[137]</td>
</tr>
<tr>
<td>11.</td>
<td><em>Murraya koenigi</em></td>
<td>Leave with 95% ethanol</td>
<td><em>S. typhi</em> <em>B. cereus</em> <em>C. albicans</em></td>
<td>D D ND D D D NT</td>
<td>[108]</td>
</tr>
<tr>
<td>11.</td>
<td><em>Baliospermum montanum</em></td>
<td>Leave with ethanol</td>
<td><em>S. aureus</em> <em>P. aeruginosa</em> <em>A. formicans</em> Klebsiella aerogenes <em>E. coli</em> Vibrio cholerae</td>
<td>D ND D D D D D</td>
<td>[139]</td>
</tr>
<tr>
<td>12.</td>
<td><em>Callistemon viminalis</em></td>
<td>Leaves with methanol</td>
<td>Gram-negative (<em>E. coli, S. typhi, P. aeruginosa</em> and <em>P. vulgaris</em>) Gram positive (<em>B. cereus, S. aureus</em>, and <em>B. subtilis</em>)</td>
<td>ND D D D D D NT</td>
<td>[111]</td>
</tr>
<tr>
<td>13.</td>
<td><em>Lantana camara</em></td>
<td>Leave with methanol</td>
<td>Bacteria (<em>K. pneumoniae, B. subtilis, P. aeruginosa</em> and <em>S. aureus</em>) Fungi (<em>A. fumigatus</em> and <em>A. flavus</em>)</td>
<td>ND D D D ND NT D</td>
<td>[106]</td>
</tr>
<tr>
<td>14.</td>
<td><em>Bauhinia variegata</em></td>
<td>Stem bark with methanol</td>
<td><em>S. epidermidis</em> <em>S. flexneri</em> <em>E. coli</em> <em>P. aeruginosa</em> <em>S. aureus</em> <em>B. subtilis</em></td>
<td>D D D D NT ND D</td>
<td>[140]</td>
</tr>
<tr>
<td>15.</td>
<td><em>Suaeda maritima</em></td>
<td>Leaves with acetone</td>
<td><em>V. cholerae</em> <em>B. subtilis</em> <em>E. coli</em> <em>S. epidermidis</em></td>
<td>D D ND ND NT ND D</td>
<td>[141]</td>
</tr>
</tbody>
</table>

(Table 2) Contd....
compounds. Table 2 shows the frequently reported medicinal plants with respective extracted solvents, antimicrobial effects and the classes of revealed phytochemicals.

9. BIOLOGICAL EFFECTS OF MEDICINAL PLANT EXTRACTS

Natural products obtained from medicinal plants have been used as a source of biologically active compounds [10, 114]. Currently, the rampant enhancement of drug resistant pathogenic microorganisms has increased the search for biologically active substances from medicinal plants [115]. Scientific reports showed that various plants have been investigated for the evaluation of phytochemical constituents and antimicrobial properties. Most of the reports have been found in a dispersed way; this paper attempts to compile some of the biologically active medicinal plants. Accordingly, as shown in Table 3, some potent medicinal plants have been selected based on scientific finding as reported earlier. The parts of plant used, type of solvent used during the extraction, amount of dosage at which each extract is effective against the tested organisms and other biological effects have been collected and arranged in Table 3.

Table 3. Active concentration and biological effects of selected medicinal plants.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Name of the Plant</th>
<th>Parts Used</th>
<th>Type of Extracts</th>
<th>Concentration</th>
<th>Biological Effects of the Extracts</th>
<th>Refs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vanilla planifolia</td>
<td>Seed</td>
<td>Methanol extraction</td>
<td>100 µl/ml</td>
<td>Interfering the quorum sensing system of Chromobacterium violaceum CV026</td>
<td>[144]</td>
</tr>
<tr>
<td>2</td>
<td>Cryptogramma crispa</td>
<td>Whole plant</td>
<td>Hexane</td>
<td>2500 µg/ml</td>
<td>6 mm zone of inhibition against Vibrio cholerae</td>
<td>[34]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Methanol</td>
<td>1250 µg/ml</td>
<td>5.5 mm zone of inhibition against V. cholerae</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Chloroform</td>
<td>625 µg/ml</td>
<td>7 mm zone of inhibition against V. cholerae</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Combretum microphyllum</td>
<td>Leaves</td>
<td>Methanol extract</td>
<td>50 µg/ml</td>
<td>35.67 mm zone of inhibition against S. typhimuriumTA98</td>
<td>[145]</td>
</tr>
<tr>
<td>4</td>
<td>Avicennia marina</td>
<td>Leaves</td>
<td>Chloroform, ethyl acetate, and methanol</td>
<td>5 mg/ml</td>
<td>The group marked zones of inhibition (431.75±10.1) mm² against the Gram-positive S. aureus bacteria</td>
<td>[146, 147]</td>
</tr>
<tr>
<td>5</td>
<td>Melia azedarach</td>
<td>Flower</td>
<td>Petroleum ether</td>
<td>500 µg/ml</td>
<td>Active against the Gram-negative species of the Klebsiella, Proteus, Enterobacter, Escherichia, Salmonella, and Shigella.</td>
<td>[148]</td>
</tr>
<tr>
<td>6</td>
<td>Adansonia digitata</td>
<td>Leaves</td>
<td>Methanol</td>
<td>0.72 µg/ml</td>
<td>Active as antiviral agent</td>
<td>[149]</td>
</tr>
<tr>
<td>7</td>
<td>Balanites aegyptiaca</td>
<td>Root and bark</td>
<td>Hexane, chloroform, methanol and water</td>
<td>3.49 µg/ml</td>
<td>The antimalarial effect with $&gt;$5.73 selective index value</td>
<td>[150]</td>
</tr>
</tbody>
</table>

Table 3 Contd....
<table>
<thead>
<tr>
<th>S. No.</th>
<th>Name of the Plant</th>
<th>Parts Used</th>
<th>Type of Extracts</th>
<th>Concentration</th>
<th>Biological Effects of the Extracts</th>
<th>Refs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Acacia nilotica</td>
<td>Herbal part</td>
<td>Ethanol</td>
<td>9.75 µg/ml</td>
<td>Active against <em>S. typhimurium</em> ATCC 1331</td>
<td>[151]</td>
</tr>
<tr>
<td>9</td>
<td>Baccaurea lanceolata</td>
<td>Stem and leave</td>
<td>Dichloromethane and methanol</td>
<td>400 µg/ml</td>
<td>Zone of inhibition against (<em>E. coli</em> 7 mm, <em>P. aeruginosa</em> 8.3 mm, <em>S. enterica</em> 7 mm, <em>B. cereus</em> 9.6 mm and <em>S. aureus</em> 7 mm)</td>
<td>[152]</td>
</tr>
<tr>
<td>10</td>
<td>Cupressus sempervirens</td>
<td>Aerial part</td>
<td>Water for essential oil and methanol for crude</td>
<td>250 µg/ml</td>
<td>Crude extracts against <em>E. feacalis</em> and essential oil against <em>S. aureus</em></td>
<td>[153]</td>
</tr>
<tr>
<td>11</td>
<td>Orthosiphon aristatus</td>
<td>Leaf</td>
<td>Ethanol extract</td>
<td>256 µg/ml</td>
<td>Effective against <em>S. aureus</em>, <em>E. feacalis</em>, and <em>P. aeruginosa</em></td>
<td>[154]</td>
</tr>
<tr>
<td>12</td>
<td>Cissus quadrangularis</td>
<td>Aerial</td>
<td>Methanol extract</td>
<td>24.38 mg/ml, 48.75 mg/ml, 390 mg/ml</td>
<td>Inhibit bacteria such as <em>S. aureus</em>, <em>E. coli</em>, <em>P. aeruginosa</em> and <em>K. pneumoniae</em></td>
<td>[155]</td>
</tr>
<tr>
<td>13</td>
<td>Myrcia tomentosa</td>
<td>Leaves</td>
<td>Fractions of hexane, ethanol, dichloromethane, ethyl acetate and aqueous</td>
<td>&gt;1000 µg/ml</td>
<td><em>E. coli</em> ATCC 8739, <em>E. cloacae</em> HMA/FTA502, <em>E. coli</em> ATCC 11229, <em>E. aerogenes</em> ATCC 13048, <em>Serratia marcescens</em> ATCC 14756</td>
<td>[156]</td>
</tr>
<tr>
<td>14</td>
<td>Garcinia mangostana L.</td>
<td>Peels</td>
<td>n-Hexane fraction</td>
<td>4.58 µmol/L and 9.15 µmol/L</td>
<td>Active against three strains of <em>S. aureus</em> (NCTC6571, MSSA15981, and MRSA252)</td>
<td>[157]</td>
</tr>
<tr>
<td>15</td>
<td>Sesbania grandiflora</td>
<td>Leaves</td>
<td>Water extract</td>
<td>40 µg/ml</td>
<td>The spectroscopic result revealed that effective against the <em>S. aureus</em> biofilm formation</td>
<td>[158]</td>
</tr>
<tr>
<td>16</td>
<td>Salvia somalensis</td>
<td>Aerial part</td>
<td>Essential oil fractionated</td>
<td>1.7 mg/ml better and 17.04 mg/ml common</td>
<td>Antimycotic activities against <em>Microsporum gypseum</em>, <em>Microsporum canis</em>, <em>Aspergillus flavus</em>, <em>Trichophyton mentagrophytes</em>, and <em>Candida albicans</em></td>
<td>[159]</td>
</tr>
<tr>
<td>17</td>
<td>Digitalis grandiflora</td>
<td>Leaves</td>
<td>Hexane extract</td>
<td>3 mg/ml</td>
<td>Inhibit the <em>S. aureus</em> and <em>E. coli</em> with 11.86% and 78.71% survival index.</td>
<td>[88]</td>
</tr>
<tr>
<td>18</td>
<td>Aristea ecklonii</td>
<td>Leaves</td>
<td>Bulk extract</td>
<td>156 µg/ml</td>
<td>Effective against the <em>P. aeruginosa</em> ATCC 27858, <em>S. aureus</em> ATCC 2592 and MRSA ATCC 43300</td>
<td>[160]</td>
</tr>
<tr>
<td>19</td>
<td>Poria cocos</td>
<td>Dry aerial part</td>
<td>Ethanol extract</td>
<td>0.01 mg/ml, 0.1 mg/ml and 1 mg/ml</td>
<td>Extracts are effective against <em>A. fumigatus</em> ATCC46645, <em>C. albicans</em> MEDINA collection, <em>P. aeruginosa</em> PAO-1 and <em>S. aureus</em> EPI-167</td>
<td>[161]</td>
</tr>
<tr>
<td>20</td>
<td>Ocimum sanctum</td>
<td>Leaves</td>
<td>Ethanol extracts</td>
<td>0.156 mg/ml</td>
<td>Inhibit the growth of <em>S. typhi</em>, <em>S. paratyphi</em> and <em>S. aureus</em></td>
<td>[162]</td>
</tr>
<tr>
<td>21</td>
<td>Piper nigrum</td>
<td>Leave powder</td>
<td>Ethanol extracts</td>
<td>156.25 µg/ml</td>
<td>Inhibit <em>B. subtilis</em> and <em>S. aureus</em></td>
<td>[163]</td>
</tr>
<tr>
<td>22</td>
<td>Camellia sinensis</td>
<td>Leaves</td>
<td>Distilled water and methanol extracts</td>
<td>100 µl/ml</td>
<td><em>Pseudomonas species</em> and <em>S. aureus</em></td>
<td>[164]</td>
</tr>
<tr>
<td>23</td>
<td>Matricaria chamomilla L.</td>
<td>Whole plant</td>
<td>Ethanol, diethyl ether and hexane extracts</td>
<td>7.5 µg/ml</td>
<td>Extracts are active against <em>E. coli</em> O157, <em>S. typhi</em>, <em>B. cereus</em>, <em>S. aureus</em>, <em>A. flavus</em>, and <em>C. albicans</em></td>
<td>[70, 165]</td>
</tr>
<tr>
<td>24</td>
<td>Moringa oleifera</td>
<td>Leaves</td>
<td>Aqueous extract</td>
<td>100 mg/ml</td>
<td>The aqueous extracts exhibits the bactericidal properties towards <em>S. aureus</em>, <em>B. cereus</em>, <em>P. aeruginosa</em>, <em>E. coli</em>, <em>S. typhi</em>, <em>K. pneumonia</em>, <em>Proteus vulgaris</em> and <em>E. cloacae</em></td>
<td>[166]</td>
</tr>
<tr>
<td>25</td>
<td>Moringa oleifera</td>
<td>Leaves</td>
<td>Aqueous and ethanol extracts</td>
<td>10 g/190 ml and 20 g/180 ml</td>
<td>Showed broad spectrum antibacterial activity towards both Gram-positive and Gram-negative pathogenic bacteria</td>
<td>[167]</td>
</tr>
<tr>
<td>26</td>
<td>Moringa oleifera</td>
<td>Leaves</td>
<td>Ethanol-water extract</td>
<td>0.6 to 10 mg/ml</td>
<td>Bactericidal activity to <em>E. coli</em> and <em>Shigella flexineri</em></td>
<td>[168]</td>
</tr>
</tbody>
</table>

**CONCLUSION AND FUTURE PERSPECTIVES**

Plant-derived constituents have been recognized based on the presence of various biological properties. Most of the reported medicinal plants possess antibacterial, antifungal, anticancer and antioxidant properties. The plant material has several substances, particularly phytochemicals which
contribute to the major biological effects. Classes of phytochemicals such as alkaloids, tannins, saponins, flavonoids, terpenoids, steroids and glycosides are frequently isolated from medicinal plants. Both the fractionated and non-fractionated plant constituents exhibit antibacterial, antifungal and antioxidant properties. Based on several reports, the repeated positive effects of microbial inhibition have been observed against *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Escherichia coli*, Bacillus species, *Salmonella* species, *Shigella* species, and *Candida albicans*. The levels of sensitivity towards the bioactive substances vary depending on the nature of cell membrane constituents. Moreover, the method of isolation, purification and characterization determine the biological properties of bioactive substances. Understanding the advanced methodology of retaining bioactive substances, the *in-vitro* and *in-vivo* tests of biological properties have contributed to the investigation of potential drugs obtained from medicinal plants. Furthermore, the rampant antibiotic resistance needs immediate exploration of new potent drugs. Naturally isolated compounds are major sources of active drug which can control this problem. Even if the costs of isolation and purification of naturally derived compounds are high; their effectiveness compensates in treating drug resistant microbes. Phytochemicals obtained from plant products serve as key antimicrobial drugs. Understanding effective techniques for isolating and purifying the compound which is relevant against multidrug resistant pathogens is important for the development of antibiotics. The procedure and methodology for the purification of compounds and their chemical structure elucidation are crucial for the improvement in drug discovery.

**LIST OF ABBREVIATIONS**

FTIR = Fourier Transform Ion Cyclotron Resonance  
GC-MS = Gas Chromatography-Mass Spectroscopy  
HPLC = High Performance Liquid Chromatography  
IR = Infrared  
NMR = Nuclear Magnetic Resonance  
TLC = Thin Layer Chromatography

**AUTHORS’ CONTRIBUTIONS**

All the authors were involved in literature search, writing and editing the manuscript.

**CONSENT FOR PUBLICATION**

Not applicable.

**FUNDING**

The authors deeply acknowledge, the Department of Biotechnology, School of Engineering and Technology, Sharda University, Greater Noida-201306 U.P., India for financial support.

**CONFLICT OF INTEREST**

The authors declare no conflict of interest, financial or otherwise.

**ACKNOWLEDGEMENTS**

Declared none.

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*Current Traditional Medicine, 2020, Vol. 6, No. 1* 35


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