REVIEW ARTICLE

Antimicrobial Activity of Medicinal Plants: A Weapon to Combat Multi-Drug Resistant Pathogens

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Abstract

Medicinal plants are extensively used in traditional systems of medicine for the treatment of different ailments. Bio-active compounds of plants and herbs show excellent antimicrobial properties against different pathogens. Plant extracts are known to control microbial growth by their anti-quorum sensing and anti-biofilm formation activities. The emergence and rapid spread of antibiotic resistance in bacterial pathogens and the evolution of new multi-drug resistant strains of disease-causing microorganisms are of remarkable alarm to the healthcare systems across the globe. Therefore the antimicrobial properties of the plant extract may represent an important alternative therapeutic route to conventional drugs. Phytochemical analysis of extract also exclusively facilitates understanding their biochemical and molecular nature for drug discovery shortly. The article focuses on the antimicrobial activity of some selected medicinal plants against the most common microbial pathogens, including clinical multi-drug resistant (MDR) bacteria.

Keywords*:* Antimicrobial activity, Bio-active compounds, MDR bacteria, Medicinal plants, Traditional medicine.

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Introduction

Since the dawn of civilization man and plants have had a deep relationship for food, timber, spices, and drugs. Ethnic communities across the globe have been enriched by their own culture in the form of traditional healthcare systems. Indian traditional systems of medicine are based on Ayurveda, Yoga, Unani, Siddha, and Homoeopathy (Prasad, 2002; Ravishankar and Shukla, 2007; Neba, 2011; Teka *et al*., 2020). Different physical ailments and their treatments have been cited in the great *Charaka Samhita*, the ancient Indian comprehensive medical text of Ayurveda (Bhavana and Shreevathsa, 2014). According to World Health Organization (WHO), about 75% of the world's population and about 80% population of the developing countries depend directly on herbal drugs for their primary healthcare. Different parts of the medicinal plants, including roots, leaves, fruits, seeds, or whole plants, have been used as therapeutic herbal drugs. Traditional healers or *Baidhya* are advising to take the folk medicines through different ethno-medicinal formulations such as plant extract, decoction, paste, powder, and infusion for its excellent anti-inflammatory, anti-diarrhoeal, antioxidant, and antimicrobial properties (Uprety *et al*., 2012; Dolatkhahi *et al*., 2014; Pan *et al*., 2014; Some *et al*., 2017). The traditional systems of medicine are getting advantages in healthcare due to fewer side effects, excellent curative treatment for several chronic diseases, and high cost of new drugs (Pandey *et al*., 2013; Some and Mukherjee, 2018). Most of the plants contain a variety of bio-active compounds. Ethno-botany and ethno-medicinal investigations are now acknowledged most efficient techniques for updating or refocusing the data on medicinal plants reported in previous research for the possible extraction of useful bio-active compounds (Thirumalai *et al*., 2009). These phytochemicals showed excellent antimicrobial activity against various Gram-positive and Gram-negative bacteria (Mahasneh and El-Oqlah, 1999; Srinivasan *et al*., 2001; Das *et al*., 2010). In addition to the phytochemicals in plant extract inhibits microbial growth by interfering cell-cell communication processes, which is generally termed as Quorum Sensing (QS) (Bacha *et al*., 2016). Several plant antimicrobial peptides (AMPs) in roots, seeds, flowers, stems, and leaves showed wonderful antimicrobial effect against different viruses, bacteria, fungi, protozoa, parasites by interaction with phospholipids and membrane permeabilization (Nawrot *et al*., 2014). The emergence of antibiotic resistance in microorganisms establishes a serious health issue due to several factors, including misuse and overuse of antibiotics. The association of antibiotic resistance genes with many mobile genetic components including plasmids, transposons, integrons, and gene cassettes, has facilitated the rise of drug resistance in bacteria. Steps can be taken at all levels of society to reduce the impact and limit the spread of resistance (White, 2009; Elisha *et al*., 2017).

Therefore, the scientific community has focused their keen interest in pharmacognosy where different bioactive compounds are being screened from plant extract to use as an alternative medicine to combat microbial infection. In this context, various researches have been reported simultaneously in the literature. Full elaboration goes beyond the reach of this inquiry as the present review article is unique to selected plants or microbes. The present article focuses on traditional uses of medicinal plants, bioactive compounds in medicinal plants, and the promising antimicrobial activity of plant extract.

Traditional Uses of Medicinal Plants

Ethno-botanical research is indispensable to exploring the traditional uses of plants for medicinal purposes. In this context, Tefera and Kim (2019) explored the traditional uses of medicinal plants among the ethnic communities in Southern Ethiopia. They observed that 105 medicinal plants belonging to 52 families and 96 genera had been used to treat human and livestock ailments, including gastrointestinal, dermatological, skeletomuscular, respiratory, and parasitic diseases. Most of the plants of Fabaceae family followed by Lamiaceae family have been utilized in primary healthcare system. Another ethno-botanical survey was conducted for the documentation of traditional knowledge in Northeastern Ethiopia. A total of 91 medicinal plant species belonging to 51 families have been used to cure 38 human diseases and 12 livestock ailments. The leaf is the most frequently used plant part in the preparation of herbal drug. *Ocimum urticifolium* Roth has been used as the most preferred plant species in therapeutic practice followed by *Withania somnifera* (L.) Dunal and *Zehneria scabra* Sond. (Osman *et al*., 2020). An ethno-medicinal study has shown that *Euclea divinorum* Hiern, *Tylosema fassoglensis* (Schweinf.) Torre & Hillc., *Carissa edulis* (Forssk.) Vahl, *Harrisonia abyssinica* Oliv., *Zanthoxylum gilletii* (De Wild.) P.G. Waterman, and *Warburgia salutaris* (G. Bertol.) Chiov. have been predominantly used in respiratory diseases by the people of Kisumu East Sub County of Kenya (Mailu *et al*. 2020). Some popular therapeutic plants that have been used traditionally are presented in Table 1.

Bio-active Compounds in Medicinal Plants

Medicinal plants produce bio-active compounds due to secondary cellular metabolism classified into four major

Table 1: Traditional uses of medicinal plants.

Botanical Name	*Family*	*Use Parts*	*Medicinal Uses*	*References*
Aloe vera L.	Asphodelaceae	L	Leaf extract has been used in dermal problems.	Abdelhalim *et al*., 2017
Amaranthus graecizans L.	Amaranthaceae	L	Leaves have been used as laxative.	Mahmoud and Gairola, 2013
Boerhavia diffusa L.	Nyctaginaceae	L, R	Extract of leaves and roots have been used in gastrointestinal, respiratory, cardiovascular, and nephrological problems.	Mishra *et al*., 2014
Bryophyllum pinnatum (Lam.) Kurz.	Crassulaceae	L	Leaf extract has been used to cure wounds and burns.	Saini *et al*., 2016
Caesalpinia decapetala (Roth.) Alston	Fabaceae	R	Decoction of root has been used in menstrual problems.	Mahwasane *et al*., 2013
Cannabis sativa L.	Cannabinaceae	S	Seed extract has been applied in rheumatoid problem, neurological, and rectal problems.	Uniyal *et al*., 2006
Chenopodium album L.	Chenopodiaceae	Wp	Plant extract has been used in gastrointestinal and nephrological problems.	Aziz *et al*., 2018
Eucalyptus obliqua L'Hér.	Myrtaceae	L	Decoction of leaf has been applied to cure upper respiratory infection.	Morales *et al*., 2016
Justicia adhatoda L.	Acanthaceae	L	Leaf extract has been used in respiratory problems.	Vidyarthi *et al*., 2013
Mentha piperita L. Huds.	Lamiaceae	L	Decoction of leaves has been used in gastrointestinal troubles.	Abdelhalim *et al*., 2017
Mimosa pudica L.	Mimosaceae	R	Root extract has been used in urinary incontinence and bladder infection.	Nandagoapalan *et al*., 2015
Momordica charantia L.	Cucurbitaceae	F	Fruit extract has been used as anti-diabetic and blood purifier.	Mahomoodally, 2013
Smilax aspera Wall.	Smilacaceae	R	Root extract has been used in sexually transmitted diseases and dermal problems.	Vidyarthi *et al*., 2013
Solanum indicum Burm.	Solanaceae	L, R	Root is dried to form powder and blended to form paste with lemon juice. It has been used in eye disease. Leaf extract has been used for cold and cough.	Vidyarthi *et al*., 2013
Vitex negundo L.	Verbenaceae	L	Leaves are boiled in water. Steam is inhaled for cold, cough, and sinusitis.	Vidyarthi *et al*., 2013

Abbreviations: F: Fruit; L: Leaf; R: Root; S: Stem; Wp: Whole plant classes like alkaloids, glycosides, polyphenols, and terpenoids (Ahmed *et al*., 2017). The foremost phytochemicals isolated from *Chenopodium album* L. include phenols, alkaloids, glycosides, saponins, and flavonoids, having an excellent pharmacological activities (Poonia, 2021). The primary phytochemical screening of the leaf extract of *M. pudica* L. exhibited the existence of bio-active components such as terpenoids, flavonoids, glycosides, alkaloids, quinines, phenols, tannins, saponins, and coumarins (Gandhiraja *et al*., 2009; Rajendran and Sundararajan, 2010; Ahmad *et al*., 2012). Apart from antimicrobial activity, flavan-3-ols from cocoa (*Theobroma cacao* L.) plant are related to a reduced risk of cadio-vascular diseases, diabetes mellitus, insulin resistance, as well as improvements in lipids, endothelial-dependent blood flow and blood pressure and systemic inflammation (Fraga *et al*., 2019). It has been noted that the yield of non-polar phytochemicals in aqueous extract was recorded quite lower than the alcoholic extract due to polarity differences between the two solvents. The plant extract of *Cynodon dactylon* (L.) Pers exhibited 12.2% glycosides, 6.3% tannins, 0.1% alkaloids, 1.0% resins, 10% free reducing sugar, and 12% total reducing sugar, respectively (Jolly and Narayanan, 2000). A study has shown that the values of terpenoids & phenolics, alkaloids, quaternary alkaloids & N-oxides and fats & waxes were recorded as 5.54067%, 2.3673%, 17.3223%, and 1.6733%, respectively in the plant extract of *Tridax procumbens* (L.) L. (Shaikh, 2018). In another study, Fahal *et al*. (2018) measured the amounts of alkaloids, flavonoids, saponins, sterol, and tannins with the values of 3.1% (± 0.004), 5.2 % (± 0.003), 6.5% (± 0.1), 4.7% (± 0.002), and 22.9% (± 0.01), respectively in the crude extract of the pod of *Moringa oleifera* Lam. The name and chemical structures of some common bio-active compounds are presented in Fig 1. The qualitative and quantitative data of bio-synthesized active compounds in medicinal plants are displayed in Table 2. Several researchers have screened the phytochemicals from different medicinal plants using various analytical techniques. A brief account of phytochemicals in medicinal plants is presented in Table 3.

Antimicrobial Activity

The secondary metabolites or bioactive compounds in medicinal plants have excellent therapeutic potency against microbes. Tannins, terpenoids, alkaloids, flavonoids, and saponins exhibited excellent antimicrobial activity against bacteria, fungi, and protozoa (Oladeji, 2016). The protocol of plant extract-mediated antimicrobial activity is represented in Scheme 1.

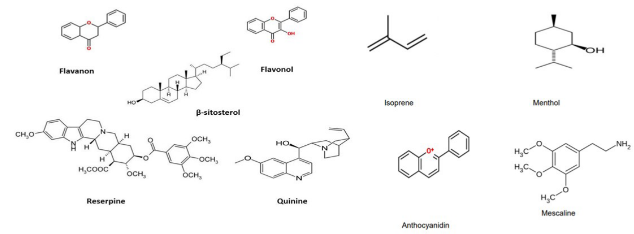


Fig 1: Chemical structure of bioactive compounds in the medicinal plant (The figure has been adapted from Mngeni, 2017).

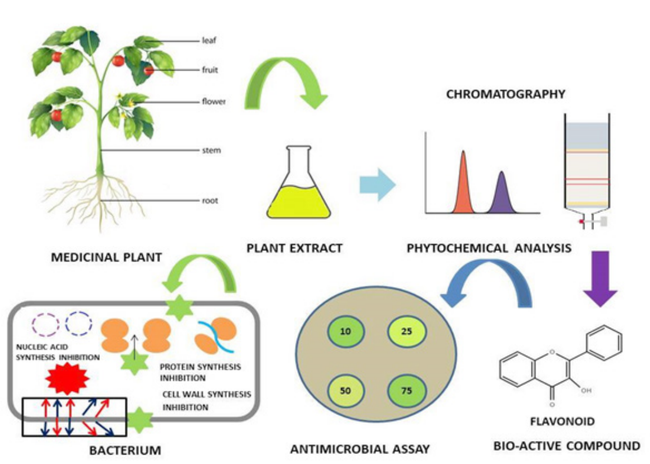
Table 2: Qualitative and quantitative data of bio-synthesized active compounds in medicinal plants.

Name of medicinal plants	*Bio-active compounds*	*Quantity (mg of GAE or QE /g of dry weight)*	*References*
Aegle marmelos (L.) Corrêa. *Cynodon dactylon* (L.) Pers. *Eclipta prostrate* (L.) L. *Moringa pterygosperma* Gaertn. *Pongamia pinnata* (L.) Pierre *Sida acuta* Burm. f. *Tridax procumbens* (L.) L.	Alkaloids, flavonoids, saponins, steroid, tannins, terpenoid, phlobatannin, and cardic glycoside.	-	Dhandapani and Sabna, 2008
Aegle marmelos (L.) Corrêa	Flavonoids	166.33 (±09.6)	Rajan *et al*., 2011
	Tannins	193.33 (±22.03)	
	Phenolic compounds	158.66 (±28.67)	
Sida acuta Burm. F	Total flavonoids in leaf extract	8.5	Jindal *et al*., 2012
	Bound flavonoids in bud extract	1.75	
Eclipta alba (L.) Hassk	Total phenolics	31.67 (±3.82)	Yadav *et al*., 2017
	Flavonoids	91.67 (±5.05)	
Pongamia pinnata (L.)	Total flavonoids	0.01398	Mishra and Pounikar, 2019
Rhodomyrtus tomentosa (Aiton) Hassk.	Total phenolics	0.7377	Ismandari *et al*., 2020
Ziziphus lotus (L.) Lam.	Total phenolics	9.4987	Yahia *et al*., 2020
	Total flavonoids	0.92055	
Ziziphus mauritiana Lam.	Total phenolics	5.3295	
	Total flavonoids	0.9026	

[GAE: Gallic Acid Equivalent; QE: Quercetin Equivalent]

Table 3: Phytochemicals present in medicinal plants.

Name of medicinal plants	*Name of bio-active compounds*	*Chemical nature of compounds*	*Analytical technique used*	*References*
Calotropis gigantea (L.) Dryand.	Cardiac glycosides	Calactin, Calotropin, Cymarin, and Asclepin	LC-MS	Bhat and Sharma, 2013
Chamaerops humilis L.	Phenolic compounds	Quinic, Malic acid, Chlorogenic acids, Rutin, and Hesperidin.	LC-MS/MS	Bouhafsoun *et al.*, 2018
Cuscuta chinensis Lam.	Phenolic acids	Chlorogenic acid, Cryptochlorogenic acid, Neochlorogenic acid, Isochlorogenic acid A, B & C, and Caffeic acid.	HPLC-ESI-MS/MS	Du *et al.*, 2018
	Flavonoids	Hyperin, Isoquercitrin, Quercetin, Campherol, p-coumaric acid, Isorhamnetin, Rutin, Astragalin, and Apigeni.		
Ephedra alata Decne	Flavonoids	Luteolin-7-O-glucuronide and Myricetin 3-rhamnoside.	HPLC/MS	Al-Rimawi *et al.*, 2017
Ephedra intermedia Schrenk & C.A.Mey.	Alkaloids	Ephedrine and Pseudoephedrine.	HPLC	Gul *et al.*, 2017
Ocimum basilicum L.	Terpenoids	α-pinene, β-pinene, Limonene, Linalool, and α –terpineol.	GC-MS	Carro *et al.*, 2013
Phyllanthus emblica L.	Phenolic acid	Gallic acid	LC-MS/MS	Sawant *et al.*, 2010
	Vitamins	Ascorbic acid		



Scheme 1: Phytochemical analysis and antimicrobial activity of bioactive compounds in medicinal plants [Plant extracts (aqueous or alcoholic) are prepared from different fresh or dry parts of the medicinal plant i.e., roots, leaves, barks, flowers, fruits, and seeds. Qualitative and quantitative estimation of the bio-active compounds has been carried out by various bio-chemical tests. Chromatographic methods have been applied to screen the phytochemicals in plant extracts. The antimicrobial activity of plant extracts has been tested using agar dilution method. The MIC/MBC value has been calculated using different concentrations of the extract. The bio-active compounds become fruitful against microbes via inhibiting cell-wall, protein, and nucleic acid synthesis or disrupting the cell-membrane].

It has been observed that leaf extracts of *Acacia nilotica* (L.) Delile, *Sida cordifolia* L., *Tinospora cordifolia* (Willd.) Miers, *W. somnifera* (L.) Dunal and *Ziziphus mauritiana* Lam. exhibited strong antibacterial activity against *Bacillus subtilis*, *Escherichia coli*, *Staphylococcus aureus*, and *Pseudomonas fluorescens* as antifungal activity against *Aspergillus flavus*, *Dreschlera turcica*, and *Fusarium verticilloides* (Mahesh and Satish, 2008). Many polyphenolic constituents and alkaloids are derived from various medicinal plants, including *Asparagus falcatus* L., *Asteracantha longifolia* Nees, *Vetiveria zizanioides* (L.) Nash, *Epaltes divaricate* (L.) Cass. Moreover, *Coriandrum sativum* L. exhibited excellent antimicrobial activity against *S. aureus* (ATCC 25923), *E. coli* (ATCC 25922) *Pseudomonas aeruginosa* (ATCC 27853), and *Klebsiella pneumoniae* (ATCC 700603) (De Zoysa *et al.*, 2019). The plausible mechanisms of action include cell wall disruption, production of reactive oxygen species, biofilm inhibition, interruption in cell wall construction, DNA replication, energy synthesis, and bacterial toxin synthesis (Mickymaray, 2019). Masoumian and Zandi (2017) observed that hydro-alcoholic extract of *Myrtus communis* L. and aqueous extract of *Cinnamomum zeylanicum* Blume showed strong antibacterial activity against *S. aureus* PTCC 1764, *E. coli* PTCC 1399, *P. aeruginosa* PTCC 1310, and *Salmonella enteric* sub specie PTCC 1709 using disc diffusion method. The extract of *M. communis* L. exhibited the minimum inhibitory concentration (MIC) value at 30 mg/mL compared to penicillin. A study was reported that leaf extract of *M. oleifera* Lam. and flower extract of *Matricaria recutita* L. showed excellent antimicrobial effect against significant drug-resistant clinical isolates such as *P. aeruginosa*, *Staphylococcus* spp., *E. coli*, *Klebsiella* spp., and *Proteus mirabilis* with an MIC value ranging at 7.8–62.5 mg/mL (Atef *et al.*, 2019). Leaf extract of *Combretum collinum* Fresen has been widely used as a traditional medicine to treat wound infection in West Africa. The bio-active compound myricetin-3-*O*-rhamnoside in the leaf extract of *C. collinum* exhibited most effectiveness against *Staphylococcus epidermidis*, methicillin-resistant *S. aureus* (MRSA), and *S. aureus* (Marquardt *et al.*, 2020). Multi-drug resistance and bacterial biofilm play a significant role in persistent infections, leading to reappearances and deterioration in urinary tract infection (UTI). A study has shown that the essential oil of *Thymus zygis* L., *Origanum majorana* L., and *Rosmarinus officinalis* L. showed antibacterial and anti-biofilm activity against an uropathogen *E. coli* (Lagha *et al.*, 2019). The essential oil of these plants also exhibited excellent biofilm inhibition and eradication properties against MRSA (Ben Abdallah *et al*., 2020). Another investigation has shown aqueous acetic acid flower extract of *M. oleifera* Lam. showed strong inhibition effect against multi-drug resistant (MDR) Gram-negative Bacilli (Mandal *et al*., 2020). Ghosh *et al*. (2014) reported that aqueous leaf extract of *Psidium guajava* L. showed anti-QS activity against an opportunistic pathogen *Chromobacterium violaceum* as manifested by inhibition of violacein production. The leaf extract also inhibits the swarming motility of *P. aeruginosa*. In a review, Gaziano *et al*. (2019) demonstrated that plant extract of *Cardiospermum halicacabum* L. showed excellent antimicrobial activity against both Gram-positive and Gram-negative bacteria. The efficacy of antimicrobial activity may vary plant to plant against organism to organism due to the nature of phytochemicals. A brief account of the antimicrobial activity of different plant extract against various microorganisms is presented in Table 4.

Antimicrobial Properties of Some Common Medicinal Plants

Allium sativum L. (Garlic)

A. sativum L. has been widely used in Ayurveda due to the presence of allicin. A study has shown that allicin is active against some clinical isolates of lung pathogenic MDR bacteria, including *Pseudomonas*, *Streptococcus*, and *Staphylococcus* (Reiter *et al*., 2017). Another study suggested that garlic extract play pivotal role in checking the endodontic infections caused by *Porphyromonas gingivalis*, *Aggregatibacter actinomycetemcomitans*, and *Streptococcus mutans* (Hoglund *et al*., 2020). Nakamoto *et al*. (2020) reported that allicin, vinyldithiins, ajoenes, and diallyl polysulfides are recorded as the predominant hydrophobic bioactive compounds in garlic and showed promising anti-biofilm activity against Gram-positive and Gram-negative bacteria.

Andrographis paniculata (Burm.f.) Nees

Ethnic communities have been widely used this plant to cure upper respiratory tract infection and urinary tract infection. A study has shown that the bioactive compound, 14-Deoxy-11, 12-didehydroandrographolide at the concentration of 0.0001M inhibits 92% biofilm production by a 48-hours treatment against *P. aeruginosa* through lessening the content of extracellular polymeric substances, level of pyocyanin production, and synthesis of extracellular protease (Majumdar *et al*., 2020). Another investigation showed that the plant extract at 100 μg/mL are most effective against CTX-M-15 extended-spectrum β-lactamase-producing *E. coli* (Rasool *et al*., 2018).

Azadirachta indica A. Juss (Neem)

The plant has been traditionally used to cure gastrointestinal, uro-genital, and dermatological ailments. The plant extract has noteworthy bactericidal activity against *Helicobacter pylori*. Neem oil extract showed excellent antimicrobial activity against this pathogen with an MIC value between 25–51 μg/mL and MBC value between 43–68 μg/mL (Blum *et al*., 2019). Mustafa (2016) reported that neem leaf extract showed robust inhibition effect on the growth of *Enterococcus faecalis* compared to 2% chlorhexidine and 3% sodium hypochlorite respectively.

Calotropis gigantea (L.) Dryand.

The plant has been used as a traditional medicine to treat oral, gastrointestinal, arthritic, and dermal diseases in Indian sub-continent. Aqueous leaf extract of the plant showed excellent

Table 4: Antimicrobial activity of plant extract.

Name of the medicinal plants	*Use parts*	*Tested microorganisms*	*Zone of inhibition (ZOI) (mm)*	*References*
Calotropis gigantea (L.) Dryand.	Milky latex	*E. coli*	15 ± 1	Rahman *et al*., 2013
		Vibrio mimicus	15 ± 1.53	
		Vibrio parahemolytics	15 ± 1	
		S. aureus	9 ± 0.58	
Erythrina caffra Thunb.	Bark	*Salmonella typhimurium*	22 ± 1.3	Wintola *et al*., 2021
		P. aeruginosa	35 ± 2.1	
Mentha cervina L.	Arial parts	*S. aureus*	30 ± 1.83	Helal *et al*., 2019
		Streptococcus pyogenes	19 ± 1.83	
		E. coli	20 ± 0.8	
		S. typhimurium	19 ± 0.82	
Ocimum basilicum L.	Arial parts	*S. aureus*	20 ± 2.5	
		Streptococcus pyogenes	19 ± 1.63	
		E. coli	20 ± 1.8	
		S. typhimurium	20 ± 1.83	
Oxalis corniculata L.	Tender shoot	*E. coli*	17	Manandhar *et al*., 2019
		Salmonella typhi	13	
		Salmonella typhi (MDR strain)	16	
		K. pneumoniae	11	
		Citrobacter koseri	12	

antimicrobial activity against various pathogenic strains, including *S. aureus*, *K. pneumoniae*, *Bacillus cereus*, *P. aeruginosa*, *Micrococcus luteus*, and *E. coli* with an MIC value at 50, 25, 6.25, 3.1, 1.5 and 12.5 mg/ml (Kumar *et al*., 2010). A study has shown that quercetin-3-O-rutinoside has been measured as predominate phytochemical in the plant extract and exhibited remarkable bio-activity against Gram-positive bacteria (*S. aureus* and *B. subtilis*) than the Gram-negative (*P. aeruginosa* and *Salmonella enteritidis*) (Nenaah, 2013).

Catharanthus roseus (L.) G. Don

The antimicrobial activity of the plant extract was evaluated against pathogenic bacterial strain using agar well diffusion method. The *in-vitro* leaf callus extract exhibited antimicrobial potential against *Bacillus licheniformis* at doses of 2.0 mg/mL (Naz *et al*., 2015). Khalil (2012) reported that alcoholic extract of plant extract showed magnificent antibacterial activity against *S. aureus* followed by *E. coli* at the dosage of 100 mg/mL. Rani *et al*. (2017) observed that alcoholic method is the best extraction process compared to aqueous, chloroform, and petroleum ether method due to more solubility of bio-active compounds in this plant as because alcoholic extract showed more antimicrobial efficacy than others.

Coccinia grandis (L.) Voigt

The protease inhibitors (PI), isolated from *Coccinia grandis* (L.) Voigt., have shown antimicrobial action. A study was reported that thermo-stable PI strongly inhibited the growth of pathogenic Gram-positive and Gram-negative microbial strains, including *S. aureus*, *K. pneumoniae*, *Proteus vulgaris*, *E. coli*, and *B. subtilis* (Satheesh and Murugan, 2011). Another investigation showed that aqueous and alcoholic fruit extract showed magnificent antibacterial activity against *S. aureus*, *E. faecalis*, *E. coli*, and *P. aeruginosa* Kirby-Bauer disc diffusion method and compared to erythromycin (Sakharkar and Chauhan, 2017).

Croton bonplandianum Baill

The plant has been widely used as a traditional medicine for curing of wound infection. The fresh latex of this plant exhibited maximum growth inhibitory activity against enteric bacteria, *E. coli* (ZOI: 32 mm) and *E. faecalis* (ZOI: 30 mm) followed by aqueous and ethanol extracts of latex which exhibited maximum inhibitory activity against *Enterobacter aerogenes* (ZOI: 26 mm) than other solvent extracts. The ethanol and benzene extracts of leaf exhibited antimicrobial activity against *S. aureus* (ZOI: 20 mm). The chloroform extract of fruits showed maximum inhibitory activity against *E. coli* (ZOI: 21 mm) compared to other solvent extracts (Vennila and Udayakumar, 2015).

Curcuma sp.

Eucalyptol, epicurzerenone, and camphor are recorded as predominant bio-active compounds in the essential oil of *Curcuma caesia* Roxb. The essential oil showed a robust antibacterial activity against *B. subtilis* and *B. cereus* with an MIC at 7.5 µg/mL, while the oil exhibited antifungal activity against *Saccharomyces cereviaceae* with an MIC at 2.5 µg/ml (Paw *et al*., 2020). *Curcuma longa* L. (turmeric) is enriched with a polyphenolic compound curcumin. It is observed that curcumin caused lipid peroxidation in *S. aureus* and *E. coli*, while the bio-active compound caused redox homeostasis disparity and triggered the kynurenine pathway in *S. aureus*. Microbial DNA damage occurs due to oxidative stress in exposed curcumin cells (Adeyemi *et al*., 2020).

Phyllanthus emblica L. (Amla)

The plant is commonly known as Amla and is used as an important herbal drug in the traditional system of medicine. A report was noted that 1, 2, 3-benzenetriol is screened as a predominant bio-active compound in the fruit extract of amla and showed excellent antimicrobial effect against MDR *Salmonella typhi* and *Salmonella enteritidis* individually or synergistically with *Quercus infectoria* G. Olivier at the doses of 12.5 mg/mL (Nair *et al*., 2020). A broth dilution study observed that seed extract exhibited quorum-modulatory effect against *Chromobacterium violaceum*, *Serratia marcescens*, *P. aeruginosa*, and *S. aureus* at doses of 50 µg/mL (Patel *et al*., 2020).

Application of Botanical Disinfectant

Plant botanicals are the derivatives of plants or secondary metabolites synthesized by the plant for protective purposes. Botanical disinfectants have been commonly used in various sectors to eliminate pathogens (Hikal *et al*., 2017). A study was proved that leaf extract of Amla (*P. emblica* L.) checked the growth of *B. subtilis* in mulberry silkworm (*Bombyx mori* L.). The augmentation of silk production is boosted by spraying 10% Amla extract in silk rearing (Gore *et al*., 2014). Isaiarasu *et al*. (2011) reported that leaf extract of *Acalypha indica* L., *Ocimum sanctum* L. and *Tridax procumbens* (L.) L. controlled the microbial infections in flacherie and muscardine. Apart from mulberry silkworm, plant extract is able to control the flacherie of muga silkworm (*Antheraea assama*). It has been proved that fruit extract of *Terminalia chebula* Retz. (Extract is known as *Muga Heal*) is very much fruitful against *P. aeruginosa* AC-3, the key pathogen of flacherie in muga silkworm. The gallic acid content in Muga Heal improves the feeding behavior of this worm. It has been found that the accumulation of *Muga Heal* on the leaves of Som plant (*Machilus bombycina* King ex Hook. f.) increased the quality of cocoons and demolished the rate of pathogenic infection as well (Unni and Neog, 2012). National Research and Development Corporation, India has developed an eco-friendly botanical-based powder (Amruth) to manage grasserie and flacherie diseases. The mixture solution of powder (@2.0g/100 mL) is sprayed uniformly on mulberry leaves (@70.0 mL/kg) before feeding. The leaves are air dried and fed to silkworm (NRDC, 2018). *Bioesque* is a commercial botanical disinfectant and highly effective against a broad spectrum of microorganisms, including bacteria, viruses, and molds. Thymol, a natural monoterpenoid phenol in the oil of thyme, extracted from *Thymus vulgaris* L. is the active ingredient in *Bioesque*. Thymol is low in toxicity to humans, animals, and the environment (Clean Safely, 2020). Therefore, use of botanical disinfectants is a one-step and eco-friendly route to eliminate different pathogens.

Conclusion

Herbal extract has made significant contributions to human health as a therapeutic agent and traditionally offered a source of opportunity for new drug compounds. Infectious diseases are the leading source of morbidity and mortality across the globe. The numbers of multi-drug resistant bacteria are increasing rapidly due to the indiscriminate use of antibiotics. MDR strains are reduced susceptibility to current antibiotics. The pharmacological use of plant extracts with potential antibacterial activity can be extremely beneficial against microbial pathogens due to noble bio-active compounds. The exploration and conservation of medicinal plants are paramount to explore the investigation on drug designing on this issue. Crude plant extracts have also inhibited the growth of microorganisms through down-regulation of gene expression. It requires more investigation to minimize the emergence of resistance and to establish the most useful therapy for infection. Therefore more plants need to be investigated thoroughly to evaluate the bioactive compound in plant extracts as a potential antimicrobial drug against MDR pathogens.

Author's Contribution

SS designed the concept. MP and SS contributed equally for writing the final version of the manuscript.

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Query Report

Q1. Cross-check for accuracy/data/format, correct, and provide all references in consistent Vancouver format.

Sample reference formatted to act as an example and to maintain consistency of format (Vancouver) required

Kumar RA, Sridevi K, Kumar NV, Nanduri S, Rajagopal S. Anticancer and immunostimulatory compounds from *Andrographis paniculata*. Journal of Ethnopharmacology. 2004;92:291-295. Available from: doi.org/10.1016/j.jep.2004.03.004