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Review Article

A Review of the Antibacterial Properties and Phytochemistry of Selected Ayurvedic Plants against Gastrointestinal Bacterial Pathogens

Gagan Tiwana[1], Matthew James Cheesman[1], Ian Edwin Cock[2,3,*]

[1]School of Pharmacy and Medical Sciences, Gold Coast Campus, Griffith University, Gold Coast, AUSTRALIA.
[2]School of Environment and Science, Nathan Campus, Griffith University, Brisbane, AUSTRALIA.
[3]Centre for Planetary Health and Food Security, Nathan Campus, Griffith University, Brisbane, AUSTRALIA.

ABSTRACT

Background: Traditional Ayurvedic medicine offers a promising and largely untapped resource for the development of novel antibacterial therapies, especially in the context of gastrointestinal (GI) infections, which are increasingly complicated by antimicrobial resistance (AMR). These plants are rich in secondary metabolites such as flavonoids, phenolic acids, tannins, and terpenoids, many of which have demonstrated significant bioactivity against a range of pathogens. **Objectives:** This review highlights the antibacterial, antioxidant, and phytochemical properties of medicinal plants traditionally used in Ayurveda for managing GI infections and diarrhoeal diseases. **Materials and Methods:** A thorough literature review was using Science Direct, Google Scholar and Scopus search engines were used as sources of information. **Results:** Despite growing interest, most existing studies have evaluated either the antibacterial efficacy or the phytochemical composition of these botanicals in isolation, limiting our understanding of the link between specific compounds and therapeutic action. Furthermore, studies typically involve a narrow spectrum of test organisms, often limited to non-resistant laboratory strains, which do not reflect current clinical challenges posed by drug-resistant pathogens. Importantly, while Ayurvedic medicine commonly employs polyherbal formulations, research rarely investigates such combinations for potential synergistic or additive effects. In addition, toxicity assessments are rarely included, leaving safety profiles of many promising extracts unverified. **Conclusion:** To bridge these gaps, future research should aim to integrate phytochemical profiling with antibacterial assays, employ a broader panel of clinically relevant pathogens, including resistant strains, and systematically assess both polyherbal combinations and toxicity profiles. This comprehensive approach would enhance scientific validation of Ayurvedic botanicals and support their development into effective, evidence-based therapies for GI infections.

Keywords: Ayurvedic plants, Traditional medicine, Bacterial infections, Antibiotic resistant bacteria, Polyherbal formulations, Flavonoids, Tannins, Phytochemicals.

Correspondence:
Dr. Ian Edwin Cock
School of Environment and Science, Nathan Campus, Griffith University, Brisbane, AUSTRALIA.
Centre for Planetary Health and Food Security, Nathan Campus, Griffith University, Brisbane, AUSTRALIA.
Email: i.cock@griffith.edu.au

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INTRODUCTION

Gastrointestinal (GI) disease represents one of the most common and significant classes of bacterial infections globally. Indeed, more than 1.7 billion cases of childhood GI infections are reported annually, and it is likely that the actual figure is much higher due to the high incidence of unreported cases.[1] GI infections result in a substantial number of mortalities annually, as well as causing a significant economic burden. Whilst there are multiple antibiotic therapies that are routinely used against these pathogens in clinical settings, the widespread development of antibiotic resistance genes in multiple bacterial species[2] has resulted in their decreased efficacy (or even complete ineffectiveness) against some strains. Safe new antibiotic therapies that are effective against diarrhoea-causing bacteria are urgently needed.

Ayurveda, one of the oldest surviving therapeutic systems globally, originates in the Indian subcontinent and remains the principal therapeutic system in that region. Indeed, it is estimated that 80% of Indian and Nepalese people regularly used Ayurveda.[1,2] The system originated in India over 3000 years ago, although it has evolved considerably since that time, and it continues to evolve as new practices are incorporated. Ayurvedic therapies are based on complex herbal formulations, that may also incorporate minerals and metallic elements. In a recent manuscript, we reviewed the underlying principles of Ayurveda and reviewed the plants that are used to treat GI bacterial infections.[1] In that study, we

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identified approximately forty species that are commonly used in Ayurveda and discussed their methods of preparation and application. Additionally, that study also outlined how their use for that purpose aligned with Ayurvedic principles. Notably, whilst our previous study highlighted those species as particularly interesting, it did not report and summarise the previous studies undertaken to confirm their antibacterial activity against GI bacteria, and to verify their traditional usage. To direct further research in this field, it is necessary to identify gaps in the literature to highlight future research areas. This report extends our earlier study by reviewing previous antibacterial studies that screen the species previously highlighted due to their traditional use to treat GI illness and diarrhoea.

MATERIALS AND METHODS

The information summarised in this study was obtained from an extensive search of traditional medicine and Ayurveda books, and original peer-reviewed research studies. Google Scholar, PubMed, Scopus and ScienceDirect databases were search using the following keywords: "Ayurvedic plants", "Ayurveda", "traditional medicine", "Indian medicine", "natural medicine", "medicinal plants", "herbs", "bacterial infection", "pathogen", "antibiotic resistant bacteria", "natural products" and "natural therapy". All keywords were searched alone and in combinations with the other terms. The initial literature search was used to collate the plants used traditionally, their specific indications and their traditional and common names. Once plant species used to treat bacterial infections in Ayurvedic medicine were identified, an additional search was undertaken to locate studies that tested the effects of those species to verify their efficacy. Finally, where specific phytochemicals were identified, further searches were undertaken to identify studies that tested those compounds against bacterial pathogens relevant to human health. Only publications that satisfied the following criteria were included in this study:

- Only studies published in English are included to avoid misinterpretation.
- Plant species are only included herein if their use to treat infections caused by bacteria are specifically documented. Where the use is not clearly defined, or if they were used to treat ambiguous symptoms that could have other causes than bacterial infections, the studies were not included.
- Only traditionally used species are included in this study. Species taxonomically related to other identified species were only included if their use for the same purpose was documented.
- As Ayurveda is now practiced globally, the search was not limited to texts arising from South Asia. Studies from other regions are also included where they examine plant species identified as being traditionally used in Ayurveda.
- As Ayurveda is a constantly evolving therapeutic system, introduced plant species and imported plants are included only if their use in Ayurveda to treat bacterial infections is documented.
- The study was unbiased and had no taxonomic preferences.
- Plant species and family names were verified using the WHO Plant list online site (https://wfoplantlist.or/plant-list)

Microsoft Excel was used for data analysis. ADC Labs ChemSketch software was used to construct chemical structures of compounds with antibacterial properties.

RESULTS

Plants traditionally used to treat bacterial infections

The selected plants have been traditionally used for treating infections, supporting their relevance in antibacterial research. Their widespread availability and sustainable sourcing make them practical for further studies and therapeutic applications. Choosing commonly cultivated or easily accessible species ensures feasibility for future research and medicinal use. The plant species reviewed herein were selected based on a recent study that reviewed the use of plant-based medicines in Ayurveda to treat GI illnesses. That study highlighted thirty-nine species commonly used for that purpose, although it did not summarise the previous studies to evaluate their ability to inhibit the growth of GI bacterial pathogens. The current study extends that earlier report by reviewing previous studies examining the antibacterial properties of the previously identified plant species.

Antibacterial activities

Table 1 provides a comprehensive overview of studies evaluating Ayurvedic plant extracts against gastrointestinal pathogens. It presents key antibacterial findings, including zone of inhibition (ZOI) measurements (which indicate the extracts' effectiveness against specific bacteria) and minimum inhibitory concentration (MIC) values. These quantitative data offer crucial insights into the potency and efficacy of Ayurvedic plants formulations, reinforcing their traditional use for treating GI infections. The inclusion of such standardised parameters enhances comparability between studies and supports further exploration of these extracts for potential therapeutic applications.

Achillea millefolium Linn.

Achillea millefolium, commonly known as yarrow, is widely recognised in traditional medicine for its anti-inflammatory, analgesic and wound-healing properties.[52] Its pharmacological effects are attributed to bioactive compounds, including flavonoids, alkaloids, and sesquiterpene lactones. Traditionally, it has been used for gastrointestinal disorders, menstrual irregularities, and as a haemostatic agent.[3,52] It also exhibits

Table 1: Indian Ayurvedic plants with antibacterial studies.

Plant Species	Common/ Ayurvedic Name	Plant Parts, Extracts & its Preparation	*In vitro* Antimicrobial Studies	References
Achillea millefolium Linn. (Asteraceae)	Yarrow, Gandna, Biranjasif	Aerial parts; hexane:ether:methanol =1:1:1. **Preparation:** The extracts for the antimicrobial assay were prepared by macerating 5 g of air-dried, finely ground plant material in a solvent mixture for five days in the dark with occasional shaking. Aerial parts; essential oil (EO) **Preparation:** EO was extracted via 3-hr hydro distillation using a Clevenger-type apparatus. The EO was dried over anhydrous Na_2SO_4 and stored in sealed dark vials at 4°C.	Broad spectrum activity against *E. coli, S. aureus,* and *Salmonella enteritidis* with ZOIs ranged from 15 to 16 mm at 50 µL per disk, including paper disc diameter of 12.7 mm. Good antimicrobial activity against *B. cereus, C. freundi, E. faecalis, E. coli, S. typhimurium* and *S. aureus* with MIC and MBC ranging from 2.5-5 µg/mL and 5-10 µg/mL respectively.	3 4
Aconitum heterophyllum wall. Ex Royle (Ranunculaceae)	Atis, Atees, Ativisha	Roots; chloroform. **Preparation:** Finely powdered roots were homogenised with 1M HCl (1:10 w/v) using a mortar and pestle, then filtered through double-layered cheesecloth. The filtrate was centrifuged at 12,500 g for 20 min at 26 ± 2°C, and the supernatant was adjusted to pH 10 with 25% ammonia. The suspension was extracted three times with chloroform, and the pooled organic layer was washed with distilled water to remove ammonia. It was then dried over anhydrous sodium sulphate and evaporated using N_2 gas.	Good antimicrobial activity against S. *aureus* with ZOI's ranging from 10-12 mm at 50 and 100 µg/mL. MIC of *S. aureus* is125 µg/mL.	5
Acacia nilotica Linn. Willd (Leguminosae)	Indian gum Arabic, Babool, Black babul	Leaves, pods, bark; 80% ethanol. **Preparation:** The plant parts were washed, shade-dried for 48 hr, and ground into a fine powder. Extraction was performed using 30 g of powdered samples in 250 mL of 80% ethanol, shaken at 200 rpm for 48 hr. The extracts were filtered, concentrated via rotary evaporation, and lyophilised for 24 hr. The freeze-dried extracts were stored at 4°C and stock solutions (100 mg/mL) were prepared in dimethyl sulfoxide (DMSO) for antibacterial testing.	Leaf extract showed good antibacterial activity against two strains of *E. coli* and *S. typhimurium* and *S. enterica* at 25 mg/mL, with ZOI's ranging from 14-20 mm respectively. Leaf extract had lowest MIC and MBC values 1.5-3 mg/mL and 3.12-6.25 mg/mL respectively against above bacterial strains as compared with pods and barks extract.	6
Achyranthes aspera Linn. (Amaranthceae)	Latjira, Chirchita, Prickly Chaff flower	Leaves; 70% aqueous acetone, water. **Preparation:** Dried plant materials were ground into powder and extracted (1:20 w/v) with 70% aqueous acetone, and water, using ultrasound-assisted extraction for 1 hr. The extracts were vacuum filtered through Whatman No. 1 paper. Acetone extracts were concentrated using a rotary evaporator at 35°C and air-dried, while water extracts were freeze-dried. Acetone and water extracts for antimicrobial assays. Leaves; 50% ethanol. **Preparation:** Leaves were washed with distilled water and shade-dried for ten days. A total of 1000 g of dried leaves was ground into a fine powder and extracted three times with 50% ethanol using the cold maceration technique. The extract was concentrated using a rotary vacuum evaporator, stored at 4°C, and yielded 8.24%.	Extracts active against *E. coli, K. pneumoniae* and *S. aureus* with MIC below 0.8 mg/mL. Antibacterial activity against, *E. coli* and *S. aureus* with ZOI's ranging from 6.4 to 16.4 mm at 3 mg/mL. MIC recorded as 0.75 and 2.75mg/mL respectively.	7 8

Plant Species	Common/ Ayurvedic Name	Plant Parts, Extracts & its Preparation	*In vitro* Antimicrobial Studies	References
Azadirachta indica A. Juss (Meliaceae)	Neem, Indian lilac	Leaves; hexane, methanol, chloroform. **Preparation:** Leaves were washed with tap water and sterile distilled water, then chopped and air-dried on a sterile blotter under shade for 20-30 days. The dried material was coarsely powdered and extracted successively with hexane, chloroform, and methanol using a Soxhlet apparatus. The liquid extracts were concentrated under reduced pressure at 40°C using a rotary evaporator. The crude extracts were labelled and stored in a refrigerator for further study. The dried extract residues were dissolved in 0.1% DMSO (100 mg/mL), filtered through a 0.45 µm membrane, and stored in sterile brown bottles at -20°C until bioassay. Fresh leaves; water, ethanol. **Preparation:** For the aqueous extract, 225 g of fresh leaves was washed, cut into small pieces, and soaked in 250 mL of water overnight. The mixture was then filtered, and the filtrate was evaporated using a rotary evaporator, yielding 1.4 g of extract. For the ethanol extract, 25 g of fresh leaves was soaked in 50 mL of absolute ethanol for 48 hr. The extract was separated using muslin cloth, concentrated with a rotary evaporator under vacuum, and yielded 2.2 g. Both extracts were stored at 5°C for further use.	Methanol extract showed highest activity against *E. coli, K. pneumoniae,* and *E. faecalis* with ZOIs ranging from 22, 28 and 23 mm respectively. Concentration-dependent activity of water and ethanol extracts against *S. aureus* with ZOIs of 14-24 mm and 10-30 mm, respectively.	9 10
Bauhinia variegata Linn. (Ceasalpiniaceae)	Kachnar, Gurial	Leaves; petroleum ether, benzene, chloroform, ethyl acetate, acetone, ethanol, water. **Preparation:** The preparation of extracts followed methods cited in previous studies by the authors. However, those referenced papers are not available in open-access sources, limiting direct verification of the exact protocols used.	Petroleum ether and chloroform extracts showed good antibacterial against *K. pneumoniae* at concentration of 5-10 mg/mL with ZOIs 15 and 18 mm, respectively. Acetone and ethanol extracts showed activity against *E. coli* at 10 mg/mL with of ZOIs 9.33 and 11.7 mm, respectively.	11
Boerhavia diffusa Linn. (Nyctaginaceae)	Ghass, Punarnava	Leaves; aqueous, ethanol, ethyl acetate, chloroform, and methanol. **Preparation:** Leaves were washed with fresh water, shade-dried at room temperature, and ground into powder for storage. A 50 g sample of dried powdered leaves was first treated with petroleum ether, then sequentially extracted with 150 mL of ethanol, methanol, diethyl ether, chloroform, ethyl acetate, and water. The preparations were kept on a shaker for three days, after which the solvents were filtered to remove extractable substances. The filtrates were then dried at room temperature until completely concentrated.	Ethanol extract was more active against *E. coli, K. pneumoniae, S. typhi, S. flexneri* and *S. aureus* with ZOIs 9-11 mm.	12

Plant Species	Common/ Ayurvedic Name	Plant Parts, Extracts & its Preparation	*In vitro* Antimicrobial Studies	References
Berberis lyceum Royle. (Berberidaceae)	Daruhaldi, Indian berberry	Roots; aqueous, methanol. **Preparation:** Roots were shade-dried, then oven-dried at 80°C overnight and powdered. For methanol extraction, 100 g of the sample was extracted in 300 mL methanol using a Soxhlet apparatus for 4 hr below the solvent's boiling point, then concentrated via rotary evaporation. For aqueous extraction, the same sample amount was boiled in water, filtered, and stored for further use.	Extracts showed better antimicrobial activity against two strains of B. *cereus,* one *E. coli* strain and four *S. aureus* strains, with ZOIs ranging from 8-22 mm, 16 mm, and 14-28 mm at 100 µg/disk respectively. MIC of 200 µg/mL recorded against *B. cereus* and *E. coli*.	13
Brassica juncea (Linn.) Czern & Cross (Brassicaceae)	Vadisha, Indian mustard	Seeds; water, 30% ethanol. **Preparation:** Seeds were extracted using water and 30% ethanol. For the water extract, 5 g of air-dried seeds were shaken at 70°C for 20 min at 230 rpm with 100 mL deionized water. For the ethanol extract, 5 g of the sample was shaken for 3 hr at 230 rpm with 100 mL of 30% ethanol. Both extracts were filtered, evaporated under vacuum, lyophilised, and dissolved in DMSO for further investigations.	Extract showed dose-dependent antibacterial activity against *K. pneumoniae* and *Shigella* sp. with ZOIs ranging from 8-17 mm.	14
Butea monosperma (Lam.) Taub. (Fabaceae)	Dhak, Tesu,	Leaves; petroleum ether, acetone, methanol, ethanol, and water (cold and hot extracts). **Preparation:** The air-dried powdered leaves (40 g) were extracted with 400 mL of petroleum ether, acetone, methanol, ethanol, and water at 4°C, followed by solvent residue removal using a rotary evaporator. For hot extraction, 40 g of powder underwent Soxhlet extraction with 400 mL of solvent for 24 hr until the extract became colourless. After filtration and concentration, the extracts were dried in a desiccator and dissolved in 10% DMSO with a drop of Tween-80 for a final concentration of 30 mg/mL.	Hot solvent extracts showed good antibacterial activity against *E. coli, K. pneumoniae, S. typhi, Shigella* sp., *Enterococcus* sp., MRSA and VRSA with ZOIs ranging from 10-21 mm. MIC values of all hot solvent extracts ranged from 0.23 to 13.30 mg/mL, and MBC values ranged from 2.60 to 30.00 mg/mL.	15
Bombax ceiba Linn. (Bombacaceae)	Sembar, Semal	Flowers; methanol. **Preparation:** Flowers were shade-dried for 15 days at room temperature, powdered, and extracted with methanol (1.5 kg in 3 L) using a Soxhlet extractor with a 5 L round-bottom flask for 24 hr. The extract was filtered, and methanol was removed under reduced pressure, yielding 73 g of crude extract for further investigation. Stem bark; methanol. **Preparation:** Stem bark was shade-dried, cleaned with tap water and ground into powder. A 100 g sample was soaked in methanol for three days with occasional shaking, then filtered through muslin cloth and filter paper. The process was repeated three times, and the combined filtrate was concentrated using a rotary evaporator at 40°C under reduced pressure. The extract was stored at 8°C for further use.	Good antibacterial activity against *K. pneumoniae, E. coli*, and *S. aureus* in a dose-dependent manner with ZOIs between 5-11 mm at 50 µg/mL. MIC values ranged between 3.125-12.5 µg/mL. Good antibacterial activity against *B. subtilis, E. coli, S. aureus* and *S. typhi* with ZOI values between 11-13 mm at 150 µg/well.	16 17

Plant Species	Common/ Ayurvedic Name	Plant Parts, Extracts & its Preparation	*In vitro* Antimicrobial Studies	References
Cassia fistula Linn. (Fabaceae)	Amaltas, Sonalu	Leaves; aqueous, ethanol, methanol, petroleum ether. **Preparation:** Sequential extraction was performed using 250 g of dry leaf powder with solvents of petroleum ether, chloroform, ethanol, methanol, and water, using a Soxhlet apparatus. After 40 siphon cycles per solvent, the extracts were concentrated by evaporation and freeze-dried at -2°C till further use. Fruit pulp; Chloroform, hydro-alcohol. **Preparation:** The fresh pulp (25 g) was extracted with 900 mL of diluted methanol, filtered, and evaporated on a hot water bath, yielding 9.7 g of hydroalcoholic crude extract. Further extraction with chloroform was performed using a Soxhlet apparatus until exhaustion, with the chloroform extract used for isolation. The extracts were combined, filtered, and evaporated to dryness. The crude hydroalcoholic and chloroform extracts were then cooled, filtered, and concentrated for antimicrobial studies. The residues were dissolved in DMSO at different concentrations and tested for antimicrobial activity.	All extracts showed antibacterial activity against *E. coli, E. coli* O157:H7, *S. typhimurium, S. sonnei,* and *S. aureus* with ZOIs between 10-15 mm at concentration of 30 mg/mL. All extracts showed antibacterial activity against *E. coli* and *S. aureus* with ZOI values in between 12-16 mm at concentration of 25 µg/mL.	18 19
Cannabis sativa Linn. (Cannbinaceae)	Bhang, Ganja	Fiber-type strain; ethanol. **Preparation:** Plant material was air-dried in the dark under controlled conditions. 12 g of finely ground cannabis were extracted in 200 mL of ethanol with continuous stirring for 4 hr. The extract was filtered, evaporated under reduced pressure at 40°C, and resolubilised in methanol:water (5:1) for further fractionation. Seeds; 80% ethanol. **Preparation:** 1 g of seeds was extracted in 10 mL of 80% ethanol, homogenised, and shaken for 3 hr in the dark at 4°C. The mixture was then centrifuged at 4500 g for 20 min, and the supernatant was filtered (0.2 µm) and stored at 4°C in the dark until use.	Good antibacterial activity of isolated cannabidiolic acid and cannabidiol against *S. aureus*, and MRSA with MIC = 1-4 µg/mL. Inhibitory effect against the planktonic cells of the biofilm producer *S. aureus* with MIC = 1 mg/mL.	20 21
Celosia argentea Linn. (Amaranthaceae)	Red Spinach, Plumed Cockscomb, Shitivaraka, Kurantika	Roots, stems; methanol, chloroform. **Preparation:** 50 g of powdered stem and root samples were extracted separately with 350 mL of chloroform and methanol for 24 hr. The extracts were dried at room temperature and stored for further studies.	Low antibacterial activity against *S. aureus* & *E. coli* at 1000 µg/mL in agar well diffusion assay.	22

Plant Species	Common/ Ayurvedic Name	Plant Parts, Extracts & its Preparation	*In vitro* Antimicrobial Studies	References
Cissampelos pareira Linn. (Menispermaceae)	Patha, Patindu	Leaves; methanol. **Preparation:** Leaf powder (50 g) was sequentially extracted using methanol through maceration in 200 mL of each solvent with intermittent shaking for 48 hr, followed by filtration. Solvent was removed using a rotary evaporator under reduced temperature and pressure. The dry extracts were weighed, stored in airtight bottles, and kept at -20°C for future use. Roots; methanol. **Preparation:** Roots were air-dried at room temperature and ground into powder. A 150 g sample was macerated in 300 mL of methanol for four days with intermittent shaking, then filtered using Whatman No. 1 filter paper. The filtrate was concentrated and evaporated to dryness using a rotary vacuum evaporator at 40°C, followed by air drying.	Antibacterial activity against *S. typhi* and *S. aureus* with ZOIs of 7-8.5 mm at 10 µg/mL. Antibacterial activity against *E. coli, K. pneumoniae, S. aureus,* and *S. typhimurium* with ZOIs = 9-20 mm at 50 µg/mL.	23 24
Cinnamomum tamala Nees et Eberm (Lauraceae)	Tejpat, Bay leaves	Leaves; 80% methanol. **Preparation:** Extract was prepared by soaking 400 g of powdered plant material in 1.4 L of 80% methanol for three days with intermittent stirring and shaking. The extract was filtered using a Buchner funnel and concentrated with a rotary evaporator at a bath temperature below 40°C, yielding approximately 12.5% of a sticky distillate. Stem bark; aqueous, methanol, ethanol, ethyl acetate. **Preparation:** 10 g of powdered plant material was extracted using both aqueous and organic solvents. For the aqueous extract, the powder was mixed with 100 mL of distilled water, stirred for 30 min, and left at room temperature for 24 hr. It was then filtered through muslin cloth, centrifuged at 5000 rpm for 15 min, and re-filtered using Whatman No. 1 filter under aseptic conditions. For organic extraction, the same amount of plant material was mixed with 100 mL of ethanol, methanol, ethyl acetate, filtered through muslin cloth and Whatman No. 1 filter, and concentrated by complete solvent evaporation at room temperature to obtain pure extracts. Stock solutions of both crude aqueous and organic extracts were prepared at a final concentration of 100 mg/mL in appropriate solvents, collected in sterilised glass tubes, and stored at 4°C until use.	Good antibacterial activity against *E. coli, K. pneumoniae,* and *S. aureus* with ZOIs = 12-18 mm at 12 µL of crude extract. All extracts showed antibacterial activity against *B. cereus, S. typhi* and *S. aureus* with ZOIs = 11-20 mm. Organic solvent (ethanol, ethyl acetate, methanol) extracts exhibited MIC of 512, 2048, 256 µg/mL against *S. aureus.*	25 26

Plant Species	Common/ Ayurvedic Name	Plant Parts, Extracts & its Preparation	*In vitro* Antimicrobial Studies	References
Cinnamomum zeylanicum Linn. (Lauraceae)		Bark; chloroform, methanol, water. **Preparation:** 10 g of powdered bark was homogenised in 100 mL of water, methanol, and chloroform. Organic extracts were dried at 60°C away from sunlight, weighed, and dissolved in DMSO (20 mg/50 µL) to obtain the desired concentration. Aqueous extracts were freshly prepared; however, no specific details on their preparation were provided.	Antibacterial activity of all extracts against *B. subtilis, E. coli* and *S. aureus* with ZOIs of 5 mm and 10 mm, respectively, with 20 µL of extract.	27
Coriandrum sativum Linn. (Apiaceae)	Dhania, Chinese parsley, Cilantro	Roots; ethanol. **Preparation:** 50 g of root powder was extracted with 250 mL of ethanol using a reflux condenser in a round-bottom flask for 24 hr. The extract was collected, and excess ethanol was removed through distillation.	Antimicrobial activity against *S. typhi, S. aureus, B. cereus* and *K. pneumoniae* with ZOI = 11-20 mm at 50 µg/mL.	28
Dalbergia sissoo Roxb. (Fabaceae)	Sesam, Indian rosewood	Leaves, barks; 95% ethanol. **Preparation:** Extract was prepared by dissolving 5 g of each sample in 50 mL of 95% ethanol and left overnight for extraction. The mixture was then filtered using Whatman No. 1 filter paper, and the filtrates were air-dried to evaporate ethanol.	Bark extract showed good antimicrobial activity against *S. aureus* with ZOI = 22 mm.	29
Desmostachya bipinnata Linn. (Poaceae)	Kusha, Darbha	Roots, leaves; chloroform, methanol. **Preparation:** 10 g of each part were soaked in 100 mL of methanol and chloroform separately for 24 hr at 37°C. The extracts were filtered, and the filtrates were dried in glass beakers. The dry weight was measured, and the difference from the blank weight was calculated. A 100 mg sample was then dissolved in 1 mL of 3-5% DMSO, yielding a final concentration of 100 mg/mL.	Methanolic leaf and chloroform root extracts showed antibacterial activity against *S. aureus* with ZOI = 13 mm at 60 µL/well.	30
Desmodium gangeticum Linn. DC (Fabaceae)	Salpan, Shalparni	Whole plant; aqueous, chloroform, ethanol and methanol. **Preparation:** 50 g of were soaked in 200 mL of cold water in stoppered conical flasks for 24 hr, then filtered through Whatman No. 1 filter paper. The filtrates were evaporated in a water bath at 100°C, and the extracts were stored at 4°C. For methanol extraction, 50 g of powdered sample was soaked in 200 mL of methanol in sealed containers for 24 hr at room temperature with occasional mixing. The mixture was filtered through Whatman No. 1 filter paper. The final clear supernatant was subjected to rotary evaporation to remove methanol, then freeze-dried at -60°C under vacuum for 24 hr. The resulting extracts were stored in airtight containers at 4°C for further use.	Methanolic extract showed better antibacterial profile against *E. coli, K. pneumoniae* and *S. typhi* with ZOIs = 20-23 mm using 30 mL of 2000 mg/mL extract.	31

Plant Species	Common/ Ayurvedic Name	Plant Parts, Extracts & its Preparation	*In vitro* Antimicrobial Studies	References
Desmodium triflorum Linn. (Fabaceae)	Cherupulladi, nilamparanda, tripadi	Whole plant; aqueous, methanol. **Preparation:** 100 g of shade-dried powdered plant material was processed using both aqueous and methanolic methods. For aqueous extraction, the powder was immersed in a chloroform:water mixture (1:99) in a 1 L beaker, with chloroform added as a preservative to prevent microbial growth. The mixture was left for 72 hr with intermittent stirring, then vacuum filtered to obtain a clear greenish extract, which was concentrated under high vacuum and dried in a desiccator. For methanolic extraction, powdered plant material was packed in a Soxhlet apparatus and subjected to continuous hot percolation with 350 mL of methanol for 8 hr. The extract was then concentrated under vacuum to a semi-solid mass and completely dried in a desiccator.	Extracts showed good antibacterial activity against *E. coli* and *S. aureus* with ZOIs ranging from 9-14 mm at 50 µg/mL.	32
Dichrostachys cinerea W. & A. (Leguminosae)	Marud, Sickle bush, Viradru	Leaves; acetone, dichloromethane, ethyl acetate, methanol. **Preparation:** 5 g powdered leaves was mixed with 50 mL of dichloromethane, ethyl acetate, acetone, and methanol. The mixtures were shaken at 200 rpm for 30 min at room temperature, filtered through Whatman No. 1 filter paper, and the process was repeated three times. Extracts were dried under a stream of cold air, weighed, and reconstituted in acetone to prepare stock solutions at 100 mg/mL. Aliquots were stored at -20°C for further phytochemical and antibacterial analysis.	All extracts showed good antibacterial activity against *K. pneumoniae* and *S. boydii* with MIC values of 160-630 µg/mL and 40-160 µg/mL, respectively.	33
Dioscorea bulbifera Linn. (Dioscoreaceae)	Genti, Potato yam	Bulbils; methanol. **Preparation:** 2 Kg of air-dried sample were pulverised and extracted three times with methanol (24 hr each). The extract was concentrated under reduced pressure, yielding 90 g of dark residue, of which 80 g was used for further partitioning. However, information on the resuspension of the methanol crude extract was not available.	Extract showed good antibacterial activity against *E. coli* and *K. pneumoniae* with MIC values from 64-128 µg/mL. MBC values range from 128-256 µg/mL.	34
Dioscorea pentaphylla Linn. (Dioscoreaceae)	Ram bahra, Paspotia	Tubers; methanol. **Preparation:** Tubers were shade-dried at room temperature, powdered, and placed in a thimble for extraction. The residues were air-dried, and the dried crude extracts were stored in a refrigerator for further experimental use. However, details on the volume of solvent used and the specific extraction procedure were not available.	Fraction of methanolic extract exhibited antibacterial activity against *S. flexneri, S. typhi* and *V. cholerae* with ZOIs of 11-12 mm at 10 µg/disc. MIC = 100 µg/mL.	35
Diospyros peregrina Gruke. (Ebenaceae)	Gab, Gaub Persimmon	Fruits; methanol. **Preparation:** 600 g of powdered plant material were extracted with methanol using a Soxhlet apparatus. The extracts were evaporated under vacuum, lyophilised into a solvent-free solid mass (yield: 8.75%), and stored in desiccators. For antimicrobial studies, the extracts were dissolved in DMSO, however, information on the volume of DMSO used is not available.	Antibacterial profile against *E. coli, S. sonnei, S. dysenteriae, S. flexneri, S. boydii* and *S. aureus* with ZOIs of 7-12 mm at 200 µg/mL. MIC values for *E. coli, Shigella* strains and *S. aureus* are 10, 200, 100 µg/mL, respectively.	36

Plant Species	Common/ Ayurvedic Name	Plant Parts, Extracts & its Preparation	*In vitro* Antimicrobial Studies	References
Eclipta prostrata Linn. (Asteraceae)	Bhringraj, Bhumiraj, Ink plant	Leaves; ethanol. **Preparation:** Surface-sterilised leaves were extracted using ethanol with a Soxhlet apparatus for 24 hr each. The extracts were concentrated under vacuum with $CaCl_2$ and used for antibacterial assays. Aerial parts; hexane. **Preparation:** 500 g of powdered aerial parts were extracted with hexane using a Soxhlet apparatus. The extracts were filtered through cotton and Whatman No. 1 filter paper, then concentrated at 40-50°C under reduced pressure using a rotary evaporator, yielding 4.69 g for hexane fractions. The extracts were stored in airtight containers at 4°C and tested for antibacterial activity.	Last three fractions of ethanol extract displayed significant activity against *S. typhi* with ZOIs of 13-16 mm with 50 µL extract and MIC = 20-30 µg/mL. Good antibacterial profile against *B. cereus, E. coli, K. pneumoniae, S. aureus* and *S. typhi* with ZOIs ranging from 11-13.5 mm at 50 µL extract/well and MIC = 90-300 µg/mL.	37 38
Emblica officinalis Gaertn. (Euphorbiaceae)	Indian Gooseberry, Amla	Fruits; ethyl acetate, methanol, water. **Preparation:** Extracts were prepared by sequential cold maceration using hexane, ethyl acetate, methanol, and distilled water. 50 g of dried fruit powder was soaked in 250 mL of hexane for 24 hr at room temperature with shaking at 120 rpm. The solution was filtered through Whatman No. 1 filter paper, and the filtrate was evaporated at room temperature. The filter cake was air-dried and sequentially extracted with ethyl acetate, methanol, and distilled water, with each dried extract stored separately at 4°C. Fruits; acetone, aqueous, ethanol. **Preparation:** Extraction was conducted by oven-drying cleaned and cut fruits at 60°C for 7 days, followed by grinding into powder. 30 g of the powdered material was extracted with distilled water, ethanol, and acetone using a Soxhlet apparatus at 100°C, 70°C, and 60°C, respectively, for 8 hr. The extracts were concentrated to a final volume of 20 mL and stored at room temperature in sterile screw-capped containers until use.	All extracts showed antibacterial activity against *B. cereus* and *E. coli* with ZOIs of 8-12 mm at 50 mg/mL extract and an MIC value for *B. cereus* and *E. coli* of 6.25-25 mg/mL, respectively. Antibacterial activity against *E. coli* and *S. aureus* with ZOIs of 8-10 mm at 15 µL extract.	39 40
Euphorbia hirta Linn. (Euphorbiaceae)	Dudhi, Snakeweed, Asthma herb	Leaves; 95% ethanol. **Preparation:** Fresh leaves were air-dried for a week, ground into fine powder, and 20 g of the powder was soaked in 250 mL of 95% ethanol. The mixture was shaken every 30 min for 6 hr and left to stand for 48 hr before being filtered through Whatman filter paper. The filtrate was evaporated to dryness using a rotary evaporator, yielding 9.1%. The extract was stored below ambient temperature. For antibacterial assays, the crude extract was dissolved in 30% DMSO and diluted to concentrations of 250, 200, 150, 100, and 50 mg/mL, and stored at 15°C until use.	Extracts showed activity against *E. coli* and *S. aureus*, ZOIs = 6 and 10 mm, respectively at 100 mg/mL and MIC = 59 and 22.5 mg/mL.	41

Plant Species	Common/ Ayurvedic Name	Plant Parts, Extracts & its Preparation	*In vitro* Antimicrobial Studies	References
Ficus religiosa Linn. (Moraceae)	Ashvattha, Pipal, Jor	Fruits; ethanol, methanol. **Preparation:** 20 g of dried sample powder was extracted with 200 mL of solvents separately by incubating in a shaker at 60°C and 150 rpm for 48 hr. The mixtures were filtered using Whatman filter paper, and the filtrates were evaporated at 60°C in a hot air oven. The dried, dark green extracts were stored at 4°C.	Both extracts exhibited antibacterial activity against *B. cereus* and *E. coli* with ZOI values of 12-14 mm on using 80 µL at 50 mg/mL.	42
Ocimum tenuiflorum Linn. (Lamiaceae)	Tulsi, Holy Basil	Leaves; acetone, methanol. **Preparation:** 20 g of air-dried powdered Tulsi leaves were extracted sequentially at 4°C with 200 mL of acetone and methanol. Solvent residues were removed using a vacuum rotary evaporator. The extracts were concentrated, dried in a desiccator, and stored in 10% DMSO with a drop of Tween-20 at a final concentration of 30 mg/mL. All stock concentrations maintained at 30 mg/mL for further use.	ZOIs = 5-8 mm at 100 µL per 1 mm wells against *E. coli, K. pneumoniae* and *S. aureus.*	43
Phyllanthus niruri Linn. (Euphorbiaceae)	Bhumi amla, Chalmeri	Leaves; methanol. **Preparation:** Fresh leaves were rinsed thoroughly, oven-dried at 45°C for 4-7 days, and ground into powder. 40 g of dried powder was soaked in 400 mL of 100% methanol at room temperature (30±2°C) for three days. The mixture was filtered through muslin cloth and Whatman No. 1 filter paper, and the filtrate was concentrated using a rotary evaporator under reduced pressure to form an oily paste, which was stored in a cool, dry place until further use.	Activity observed against *B. cereus* and *S. aureus* at 100 mg/mL with ZOIs of 14-15 mm and MIC values of 3.13-6.25 mg/mL, respectively.	44
Swertia chirayita (Roxb. ex-Fleming) H. Karst. (Gentianaceae)	Chirata, Indian Gentian	Leaves, roots, stems; methanol **Preparation:** 20 g of powdered leaves, stems, and roots were extracted using methanol. The samples were soaked in 400 mL of solvent in screw-capped conical flasks and shaken at room temperature for 24 hr at 100 rpm. After filtration through muslin cloth and Whatman No. 1 filter paper, the filtrates were concentrated at 35-40°C using a water bath. The extracts were labelled and stored at 4°C. For further use, the extracts were dissolved in DMSO to prepare stock solutions at 0.5 g/mL.	Leaf and stem extracts showed antimicrobial activity against *K. pneumoniae, S. aureus* and *S. enterica* 9.5-17.5 mm and 8-13.5 mm at 50 µL extract/ well, respectively.	45
Solanum nigrum Linn. (Solanaceae)	Makoy, Black nightshade	Fruits; petroleum ether, chloroform, dichloromethane, ethyl acetate, acetone, methanol and water. **Preparation:** Dried powdered fruit samples were sequentially extracted with solvents through maceration for seven days at room temperature. The extracts were filtered and dried under vacuum using a rotary evaporator at 40 ± 5°C. The dried extracts were weighed to determine the percentage yield, redissolved in dimethyl sulphate ($DMSO_4$) for antimicrobial analysis, and stored in labelled sterile screw-capped bottles.	All extracts exhibited antibacterial activity with ZOIs of 3.5-16 mm at 20 mg/ mL against *E. coli, S. aureus* and *S. typhi.*	46

Plant Species	Common/ Ayurvedic Name	Plant Parts, Extracts & its Preparation	*In vitro* Antimicrobial Studies	References
Tephrosia purpurea (Linn.) Pers. (Fabaceae)	Fish poison, Wild indigo Sarphonk, Sharpunkha	Roots; 80% methanol. **Preparation:** Shade-dried plant materials were powdered and then defatted with petroleum ether (60-80°C) using a Soxhlet apparatus. The defatted mixture was further extracted with 80% methanol in a Soxhlet for 72 hr. The solvent was removed by distillation under suction, and the semisolid mass was dried using a rotary evaporator, yielding solid residues of 7.3%. The dried extracts were dissolved in dimethyl sulfoxide (DMSO) for further study.	Activity observed against *S. aureus* and *S. typhimurium* at 100 µg/mL with ZOIs of 8-9 mm.	47
Terminalia bellirica (Gaertn) Roxb. (Combretaceae)	Bibhitaki, Bahera, Beleric Myrobalan	Fruits; water, methanol. **Preparation:** Fresh dry fruits were purchased, deseeded, and ground into a fine powder. For aqueous extraction, the powder was mixed with sterile distilled water at a concentration of 1 g/5 mL (pH 6.9) and stored in a refrigerator. For methanol extraction, 2 kg of dry fruit powder was soaked in 5 L of absolute methanol for 48 hr. The extract was concentrated through multiple distillation cycles to obtain a thick brown paste. 1 g of the methanol-free residue was dissolved in 5 mL of methanol to prepare a solution with a concentration of 1 µL = 0.2 mg of T. bellirica.	Both extracts showed good activity against *E. coli, S. aureus, S. typhi* and *S. typhimurium* with ZOIs = 16-30 mm at 4 mg in 20 µL/ disc. MIC values = 250-1200 µg/mL.	48
		Fruits; water, methanol, ethyl acetate. **Preparation:** 1 g each of fruit powder was extracted with 50 mL of deionized water, methanol, or ethyl acetate. The mixtures were rolled at 30 rpm for 24 hr at room temperature and filtered through Whatman No. 54 filter paper under vacuum. Aqueous extracts were frozen at -80°C for 30 min and lyophilised for 48 hr, while methanol and ethyl acetate extracts were dried in an oven at 50°C for up to 48 hr. The dried extracts were weighed, resuspended in 10 mL of 1% DMSO, and sonicated. The solutions were sterilised by passage through 0.22 µm filters and stored at room temperature until use.	ZOIs of 9-18 mm were observed against *E. coli, B. cereus, S. sonnei, S. typhimurium, S. aureus* and *S. flexneri* at 10 µL/disc and MIC values of 250-750 µg/mL.	49
Terminalia chebula Retz. (Combretaceae)	Haritaki, Harad, Chebulic Myrobalan	Fruits; ethanol. **Preparation:** The fruit pulp (427 g) was shade-dried and soaked in ethanol for 24 hr. The ethanol extract was concentrated at low temperature under reduced pressure using a rotary evaporator to obtain a crude residue. This crude extract was dissolved in 1% DMSO for antimicrobial studies.	ZOIs of 9-13 mm at 0.5 mg/ disc were noted against *E. coli, K. pneumoniae, S. aureus* and *S. typhi.* MIC values = 48-968 µg/mL.	50
		Fruits; water, methanol, ethyl acetate. **Preparation:** 1 g each of fruit powder was combined with 50 mL of deionized water, methanol, or ethyl acetate. The mixtures were continuously rolled at 30 rpm for 24 hr at room temperature and then filtered using Whatman No. 54 filter paper under vacuum. Aqueous extracts were frozen at -80°C for 30 min and lyophilised for 48 hr, whereas methanol and ethyl acetate extracts were dried in an oven at 50°C for up to 48 hr. The dried extracts were weighed, dissolved in 10 mL of 1% DMSO, and sonicated. The solutions were sterilised by passing through 0.22 µm filters and stored at room temperature for further use.	ZOIs of 13-20 mm observed against *B. cereus, S. sonnei, S. typhimurium, S. aureus* and *S. flexneri* and MIC values of 250-750 µg/mL.	49

Plant Species	Common/ Ayurvedic Name	Plant Parts, Extracts & its Preparation	*In vitro* Antimicrobial Studies	References
Tinospora cordifolia (Willd.) Miers ex Hook.f. & Thoms. (Menispermaceae)	Guduchi, giloe	Stems; acetone, aqueous, benzene, ethanol, ethyl acetate. **Preparation:** Stems were shade-dried, crushed, and ground into fine powder. The powdered material was sequentially extracted using different solvents in a Soxhlet apparatus. The extract fractions were centrifuged, filtered, and lyophilised. The dried residues were dissolved in DMSO for antibacterial, assays.	Acetone, aqueous and ethyl acetate extracts showed ZOIs of 10-12 mm at 20 µL/disc against *K. pneumoniae*, and only acetone and ethyl acetate extracts showed ZOIs of 19-26 mm against *E. coli*. MBC of acetone extract against *K. pneumoniae* = 1.29 mg/mL, while ethyl acetate and acetone extracts showed MBC of 1.29 to 4.21 mg/mL.	51

antioxidant, antimicrobial, and gastroprotective activities, supporting its medicinal relevance.

In a previous research study, extracts of *A. millefolium* were prepared from the plant's aerial parts using equal proportions of ether, hexane, and methanol. These extracts exhibited notable antibacterial activity against *Escherichia coli, Staphylococcus aureus*, and *Salmonella enteritidis* in agar diffusion assays.[3] Notably, MIC values were not reported in that study, making potency comparisons with other studies and between extracts impossible. Further studies are required to quantify the potency of these extracts. A separate study tested an essential oil prepared from *Achillea millefolium* aerial parts and reported strong antibacterial activities against several gastrointestinal bacterial pathogens, with MIC values ranging from 2.5-10 µg/mL.[4] Notably, the aerial parts of this plant are most frequently cited to treat diarrhoea in Ayurveda (see Table 1). Therefore, extracts prepared from the aerial part of this species should be further evaluated to justify the ethnobotanical use of this species.

Aconitum heterophyllum Wall. Ex Royle

Aconitum heterophyllum, commonly known as ativisha or Indian ateech, is a perennial herb indigenous to the alpine and sub-alpine regions of the Himalayas.[53] Traditionally, its dried roots have been utilised in Ayurvedic medicine to treat multiple ailments, including fevers, respiratory disorders, and digestive issues. The therapeutic properties of *A. heterophyllum* are attributed to its bioactive alkaloids, which exhibit antipyretic, anti-inflammatory, and analgesic effects.[53] Notably, unlike other *Aconitum* species, *A. heterophyllum* is considered non-toxic, making it relatively safe for medicinal use.

Chloroform extracts prepared from *A. heterophyllum* have been reported to have good antibacterial activity against *S. aureus*, and it was postulated that this may be due to the presence of bioactive alkaloid active molecules.[5] However, relatively few studies have examined the antibacterial activity of this species, and substantially more work is required to evaluate its potential to treat gastrointestinal diseases. Furthermore, compound identification studies are required to identify potential druggable targets in this plant.

Acacia nilotica Linn.

Acacia nilotica, commonly known as babul, is a medicinal tree valued for its antimicrobial, anti-inflammatory, antidiabetic, and antioxidant properties. Various parts, including bark, leaves, and pods contain bioactive tannins and flavonoids, contributing to its pharmacological effects and traditional therapeutic applications.[54] Traditionally, the bark and pods of *A. nilotica* have been used to treat diarrhoea and other gastrointestinal problems. Interestingly, an 80% ethanolic leaf extract of *A. nilotica* had noteworthy antibacterial activity against antibiotic-resistant strains of *E. coli, Salmonella typhimurium* and *Slmonella enterica.*[6] However, that study specifically examined leaf extracts, reporting high antioxidant content but relatively low antibacterial activity compared to extracts derived from the pod and bark. Indeed, the MIC and MBC values of *A. nilotica* leaf extracts were in the ranges of 1.5 - 3.0 mg/mL and 3.12 - 6.25 mg/mL against *E. coli* and *Salmonella* strains, respectively, which is indicative of poor activity.[6]

Achyranthes aspera Linn.

Achyranthes aspera, commonly known as latjira, is traditionally used to treat various ailments, including fever, wound healing, toothache, arthritis, and gynaecological disorders.[7] Its medicinal properties are attributed to bioactive compounds such as saponins and alkaloids. Pharmacological studies have demonstrated its antimicrobial, anti-inflammatory, and analgesic activities. That study reported that 70% acetone and aqueous *A. aspera* leaf extracts had MIC values <1 mg/mL against *E. coli, Klebsiella pneumoniae* and *S. aureus.*[7] Further study is required to evaluate the potential of extracts prepared using this species against a broader panel of GI pathogens, and to determine their antibacterial mechanisms. One study reported that 50% ethanol leaf extract of *A. aspera* Linn. had good activity against *S. aureus* (MIC = 0.75 mg/mL), although it had only low activity against *E. coli* (MIC = 2.75 mg/mL). The same study also reported that

the extract contained oleanolic acid, lupeol and β-sitosterol and highlighted they potential antibacterial properties.[8] However, it is noteworthy that oleanolic acid is also toxic, and further studies are required to confirm the safety of this species for medicinal use.

Azadirachta indica A. Juss

Azadirachta indica, commonly known as neem, is a fast-growing tree native to the Indian subcontinent. Traditionally, various parts of the neem tree (leaves, flowers, seeds, fruits, roots, bark) have been utilised in Ayurvedic, Unani, and Homeopathic medicine to treat inflammation, infections, fever, skin diseases, and dental disorders.[55] Additionally, research indicates that neem exhibits immunomodulatory, anti-inflammatory, antihyperglycemic, antiulcer, antimalarial, antifungal, antibacterial, antiviral, antioxidant, antimutagenic, and anticarcinogenic activities.[55]

Methanol and chloroform leaf extracts of *Azadirachta indica* produce large ZOIs (22-28 mm) in agar well diffusion assays against *E. coli, Enterococcus faecalis* and *K. pneumoniae*. However, the concentrations of the extracts tested in that study were not stated and the potency was not quantified.[9] However, it is likely that the authors tested the extracts undiluted, and therefore the potency of the extracts is in doubt due to the presence of solvents in the assay. Another study tested water and ethanol *A. indica* leaf extracts for the ability to inhibit *S. aureus* growth in agar diffusion assays and reported concentration-dependent inhibition.[10] Notably, extracts prepared using fresh leaves had substantially higher activities than extracts prepared from dried leaves or using bark in that study. However, extracts from this species need to be more thoroughly tested against a wider panel of bacterial pathogens relevant to human health. Additionally, compound purification and characterisation studies are required to identify the bioactive components in the extracts.

Bauhinia variegata Linn.

Bauhinia variegata, commonly known as kachnar, is widely utilised in traditional medicine, particularly in Ayurveda, for managing diabetes, lymphadenopathy, goitre, tumours, and dermatological disorders. Various plant parts, including the bark, flowers, and leaves, possess pharmacological properties, attributed to bioactive compounds such as flavonoids, tannins, and saponins.[56]

Whilst this species has a history of use in Ayurveda to treat GI illness, relatively few studies have been published to verify the therapeutic potential of *B. variegata*. Leaf extracts prepared from *B. variegata* have moderate to good antibacterial activity against *K. pneumoniae* and *E. coli* in disc diffusion assays.[11] The chloroform and petroleum ether extracts tested in that study had the highest antibacterial activities against *K. pneumoniae* at 5 mg extract per disc in that study (ZOIs=15-18 mm). However, MIC values were not determined in liquid microdilution assays, making comparisons with other studies difficult. Furthermore, *B. variegata* extracts have only been tested against a very limited panel of pathogens and substantially more work is required to evaluate the potential of this species.

Boerhaavia diffusa Linn.

Boerhaavia diffusa, commonly known as punarnava, is extensively utilised in Ayurveda, Unani, and Siddha. Various parts of the plant, including roots, leaves, and aerial parts, are employed to treat a range of ailments, including inflammation, liver disorders, and kidney diseases. Phytochemical investigations have identified several alkaloids, flavonoids and rotenoids, which contribute to its pharmacological activities, including anti-inflammatory, hepatoprotective, and diuretic effects.[57]

Whilst few studies have thoroughly evaluated the potential of *B. diffusa* to treat GI diseases, ethanol leaf extracts prepared have been reported to inhibit *E. coli, K. pneumoniae, Salmonella typhi, Shigella flexneri*, and *S. aureus* growth on agar (ZOIs = 9-11 mm).[12] Unfortunately, the extract concentrations tested were not reported in that study. Additionally, neither of these earlier studies determined the MIC (or MBC) values of these extracts and further studies are required to quantify their antibacterial properties.

Berberis lyceum Royle.

Berberis lyceum, commonly known as Indian berberry, is traditionally used to treat jaundice, diabetes, eye infections, fractured bones, internal wounds, diarrhea, rheumatism, and stomach-ache. Its medicinal properties are attributed to the bioactive compound berberine, which exhibit antimicrobial, antidiabetic, and anti-inflammatory activities.[58] However, relatively few studies have thoroughly evaluated the medicinal potential of this species, and generally the methods and interpretations are dubious. In one study, water and methanol *B. lyceum* root extracts inhibited *Bacillus cereus, E. coli* and *S. aureus* growth on agar (ZOIs = 10-26 mm) when 100 µg of extracts were infused into disks.[13] Notably, this is a substantially higher amount of extract than is usually tested in agar diffusion assays and is usually not considered to be indicative of antibacterial activity. Additionally, the authors of that study quantified the potency of the *B. lyceum* methanolic root extract in microdilution assays and reported noteworthy MIC values of 200 µg/mL against *B. cereus* and *E. coli*.

Brassica juncea (Linn.) Czern & Cross

Brassica juncea, commonly known as Indian mustard, has been traditionally used for its medicinal properties in Ayurveda and traditional Chinese medicine (TCM). Various plant parts, particularly the seeds and leaves, are utilised for their stimulant, diuretic, and expectorant effects. This species is rich in bioactive glucosinolates and flavonoids, which exhibits antimicrobial, antioxidant, and anti-inflammatory activities.[59]

Nevertheless, research investigating the capacity of this species to suppress and/or eradicate GI infections has been limited. One study reported significant antibacterial activity for *B. juncea* 30% ethanol seed extracts against *K. pneumoniae* and *Shigella* spp. growth on agar (ZOIs = 8-17mm), although that study did not quantify the potency.[14] However, the authors did identify multiple phenolic compounds, including caffeic acid, *p*-coumaric acid, epigallocatechin gallate, myricetin, apigenin, quercetin-3-*O*-(caffeoyl)-glucoside and quercetin in the 30% ethanol seed extract using liquid chromatography/mass-spectroscopy (LC/MS-MS) analysis. These compounds may be responsible for the observed antibacterial activity, although this remains to be verified. Future studies are also required to evaluate the potential of this plant against a broader panel of GI pathogens, and to quantify the potency of the extracts.

Butea monosperma (Lam.) Taub.

Butea monosperma, commonly known as flame of the forest, is extensively utilised in the Ayurveda, Unani, and Siddha traditional medicine systems. Various parts of the plant, including the roots, leaves, fruits, stem bark, flowers, gum, and young branches, are employed to treat ailments like diarrhea, dysentery, inflammation, and diabetes.[60] Additionally, phytochemical studies have identified specific flavonoids, terpenoids, and glycosides, which may contribute to its pharmacological activities, including antimicrobial, anti-inflammatory, and antioxidant effects. The use of this species to treat GI illnesses may be related to these properties, although studies are required to confirm this. To date, relatively few studies have examined the potential of this species to inhibit the growth of GI bacterial pathogens. One study reported that hot solvent leaf extracts of *B. monosperma* have good antibacterial activity against *E. coli, K. pneumoniae, S. typhi, Shigella* sp., *Enterococcus* sp., methicillin resistant *S. aureus* (MRSA) and vancomycin resistant *S. aureus* (VRSA), with ZOI values ranging from 10-21 mm.[15] Furthermore, the authors of that study quantified the potency through liquid dilution assays, with MIC values of 0.2-13 mg/mL, and minimum bactericidal concentration (MBC) values of 2.6-30 mg/mL.[15] Notably, many of those MIC and MBC values are relatively high, indicating moderate to low antibacterial activity. Substantially more work is required to more fully evaluate the antibacterial properties of this species.

Bombax ceiba (Lam.) Taub

Bombax ceiba, commonly known as the red silk-cotton tree, has been widely used in traditional medicine, particularly in Ayurveda and TCM. Various parts of the plant (particularly the flowers, leaves and bark) are employed to treat ailments like fever, inflammation, diarrhea, and skin diseases.[61] Phytochemical analysis has identified bioactive flavonoids, terpenoids and phenolics, which may contribute to its pharmacological activities, including antioxidant, anti-inflammatory and antimicrobial effects.

Notably a previous study reported that *B. ceiba* flower extracts inhibit the growth of *K. pneumoniae, E. coli* and *S. aureus* in a dose-dependent manner, with ZOIs ranging from 5-11 mm at 50 µg/mL in disc diffusion assays.[16] Furthermore, the MIC value of the extracts indicated strong activity, with values in the range of 3-12.5 µg/mL. The potency of these extracts is very promising and highlight the therapeutic potential of this plant. Additionally, another study reported that a *B. ceida* methanolic stem bark extract inhibited *E. coli, S. aureus* and *S. typhi* growth on agar (ZOIs = 11-13 mm) using 150 µg of extract in agar well diffusion assays.[17] Future studies are required to evaluate *B. ceida* extracts against a substantially expanded panel of bacterial pathogens, and to identify the bioactive entities and their mechanistic pathways.

Cassia fistula Linn.

Cassia fistula, commonly known as the golden shower tree, is highly valued in traditional medicine for its diverse therapeutic applications. The fruit pulp is widely used as a natural laxative, whilst the leaves, bark, and seeds are employed for managing skin disorders, fever, and digestive issues.[62] It is rich in anthraquinones, flavonoids, and glycosides, which may contribute to its antioxidant, antimicrobial, and anti-inflammatory properties. A previous study demonstrated that aqueous, ethanol, methanol, and petroleum ether leaf extracts of *C. fistula* inhibit *E. coli, E. coli* O157:H7, *S. typhimurium, S. sonnei* and *S. aureus* growth on agar (ZOIs = 10-15 mm) at a concentration of 30 mg/mL,[18] although MIC values were not determined in that study. A separate study assessed the antibacterial efficacy of *C. fistula* fruit pulp, extracted using hydro-alcohol and chloroform, which inhibited *E. coli* and *S. aureus* (ZOIs = 12-16 mm) at a concentration of 25 g/mL.[19] Future studies are needed to quantify the potency of those extracts to allow them to be benchmarked against other studies. Furthermore, the extracts must be evaluated against a wider range of pathogens, and the bioactive components should be characterised.

Cannabis sativa Linn.

Cannabis sativa (commonly known as Indian hemp, cannabis, marijuana) is traditionally used in Ayurvedic medicine to treat digestive disorders such as indigestion, diarrhea, dysentery, and colic pain. Rich in cannabinoids including tetrahydrocannabinol (THC) and cannabidiol (CBD), it exhibits anti-inflammatory, analgesic, and antimicrobial effects, potentially aiding in gut infections by modulating gut motility, reducing inflammation, and combating harmful microbes.[63] While *C. sativa* is widely recognised in Western society for its psychoactive properties, Ayurveda also utilises it as a sedative, analgesic, and anti-inflammatory agent, as well as for managing gastrointestinal illnesses. Notably, the phytoconstituents of this species have been relatively well examined, particularly in relation to the

cannabinoids.[63] Cannabidiolic acid and CBD have been isolated from the ethanol extract of fibre-type strains of *C. sativa* and tested for their antibacterial properties,[20] with both compounds exhibiting strong antibacterial activity against *S. aureus* and MRSA (MIC values 1-4 µg/mL). These values are very promising and indicate potent antibacterial activity, further highlighting the need to screen extracts and isolated compounds from this species against a broader panel of pathogens. Additionally, an 80% ethanol *C. sativa* seed extract inhibited the biofilm formation and *S. aureus* growth (MIC = 1 mg/mL).[21] The authors of that study postulated that the biofilm inhibition activity may be due to the high content of polyphenols, predominantly caffeoyltyramine and cannabisin in the extract.[21] Notably, hemp seed extract does not affect probiotic bacteria, further indicating its therapeutic suitability for the treatment of GI diseases. CBD also inhibits the growth of *S. typhimurium* and *Salmonella newington*, with MIC values of 0.125 µg/mL against both pathogens, which compared favourably to the reference antibiotic ampicillin (MIC = 0.5 µg/mL).[64]

Celosia argentea Linn.

Celosia argentea, commonly known as plumed cockscomb, is traditionally used in various medicinal systems to treat diabetes mellitus, diarrhea, eyes disease, hypertension, and snakebite poisoning.[65] The seeds, leaves, flowers, roots and stems are utilised for their therapeutic properties. In one study, chloroform stem and root extracts of *C. argentea* were reported to inhibit *S. aureus* and *E. coli* growth (ZOI = 5 mm), at a concentration of 1 mg/mL in agar well diffusion assays, indicating low activity.[22] However, the authors did not report MIC values by micro-liquid dilution assay and further studies are required to allow the activity of these extracts to be quantified. Additionally, phytochemical evaluations and mechanistic studies are also required to evaluate the potential of this species in the treatment of GI disease.

Cissampelos pareira Linn.

Cissampelos pareira, commonly known as velvet leaf, is a climbing herb extensively utilised in Ayurveda and TCM. Various parts of the plant, including roots, leaves, and aerial parts, are employed to address urinary problems, skin infections, gastrointestinal issues, respiratory conditions, and reproductive disorders.[66] One study showed that methanolic leaf extracts of *C. pareira* inhibits the growth of *E. coli, K. pneumoniae, S. typhi* and *S. aureus* (ZOIs = 7-8.5 mm) at a concentration of 10 µg/mL.[23] Another study reported that methanolic root extracts of this plant inhibit the growth of *S. aureus, S. typhimurium, E. coli* and *K. pneumoniae* (ZOIs = 9-20 mm) at 50 µg/mL.[24] However, the absence of MIC data in those studies limits the quantitative assessment of antimicrobial activity. Reliance solely on disc diffusion is insufficient, as zone diameters are influenced by diffusion properties and do not differentiate between bacteriostatic and bactericidal effects, reducing result reliability.

Cinnamomum tamala Nees. & Eberm. and *Cinnamomum zeylanicum* Linn.

Cinnamomum tamala and *Cinnamomum zeylanicum* are important medicinal plants widely used in several traditional healing systems and culinary practices. *C. tamala* (Indian bay leaf) is commonly used in Ayurveda and Unani medicine to manage digestive disorders, diarrhea, colic, rheumatism, nausea, and vomiting.[67] The leaves are the primary medicinal part, valued for their aromatic and therapeutic properties. *Cinnamomum zeylanicum* (true cinnamon) is well-known for its role in respiratory, digestive, and gynaecological health, and is often used to alleviate indigestion, bronchitis, menstrual irregularities, and inflammation.[67] The bark is the main medicinal part, used for its antimicrobial, antioxidant, and anti-inflammatory properties. Several studies have confirmed the antibacterial properties of *Cinnamomum* spp. and highlighted the need for further studies. One study showed that *C. tamala* leaves extracted with 80% methanol exhibit good antibacterial activity against *E. coli, K. pneumoniae*, and *S. aureus* (ZOIs = 12-18 mm) when 12 µL were tested in agar well diffusion assays.[25] Unfortunately, MIC values were not reported in that study, and it is therefore not possible to compare the antibacterial activity with other studies. In a different study, aqueous, methanol, ethanol, and ethyl acetate *C. tamala* stem bark extracts were reported to inhibit the growth of *S. typhi, S. aureus, S. pyogenes* and *B. cereus* in agar well diffusion assays (ZOIs = 11-22 mm) using 100 µL of crude extracts, although only the ethanol and methanol extracts yielded low MIC values (256-512 µg/mL) against *S. aureus* in that study.[26] Similarly, antibacterial activities of water, methanol and chloroform bark extract prepared from *C. zeylanicum* were investigated against *B. subtilis, E. coli* and *S. aureus* in agar well diffusion assays. ZOI values of 5 to 10 mm were measured against each pathogen, at 20 µL,[27] and MIC value of 2.5 mg/mL against *B. subtilis* and *S. aureus* were reported. Notably, these MIC values are indicative of low to moderate antibacterial activity and highlight the need for further studies to evaluate the therapeutic potential of this genus.

Coriandrum sativum Linn.

Coriandrum sativum (coriander) is one of the most widely used culinary herbs globally and is cultivated widely. It is used in Ayurveda for managing gastrointestinal disorders, including indigestion, bloating, colic, diarrhea, and dyspepsia.[1] The roots, seeds, leaves, and stems are medicinally valuable, with the roots particularly known for their digestive, carminative, and antispasmodic properties.[68] Several studies have evaluated its antibacterial properties against bacterial GI pathogens. Indeed, ethanolic *C. sativum* root extracts inhibit the growth of *S. typhi, S. aureus, B. cereus* and *K. pneumoniae* (ZOIs = 11-20 mm) at 50 µg/mL in agar well diffusion assay.[28] Notably, MIC values were not reported in that study and further work is required to quantify the potency of those extracts, and to identify the bioactive components.

Dalbergia sissoo Roxb.

Dalbergia sissoo (commonly known as Indian rosewood or shisham) is traditionally used in Ayurveda and Unani medicine for treating gastric ulcers, diarrhea, dysentery, and indigestion.[69] The bark and leaves possess astringent, antidiarrheal, and gastroprotective properties. Rich in flavonoids, tannins, and terpenoids, it helps reduce gut inflammation and microbial infections. Whilst substantially more research is required to confirm its therapeutic activity, some studies have reported activities consistent with its traditional uses. One study reported ethanol bark extracts are strong inhibitors of *S. aureus* growth (ZOI = 22 mm), although the concentrations of the extracts were not stated in that study, and it is therefore not possible to comment on its potency.[29]

Desmostachya bipinnata Linn. and related species

Desmostachya bipinnata root decoctions are used in Ayurveda to treat diarrhoea and dysentery.[1] Several studies have screened *D. bipinnata* extracts for the ability to inhibit diarrhoea-inducing bacterial pathogens. One study tested *D. bipinnata* methanolic root and chloroform stem extracts against *E. coli* and *S. aureus* growth reported noteworthy activity (ZOIs of 9 and 13 mm, respectively) using 60 µL loads in agar well diffusion method.[30] However, MIC values were not reported, and it is therefore not possible to compare the potency between studies/plant extracts. Additionally, whole plant methanolic extracts of *Desmodium. gangeticum* Linn. DC were reported to be potent inhibitors of *E. coli, K. pneumoniae* and *S. typhi* growth in agar well diffusion assays, producing large ZOIs of 20-23 mm. Unfortunately, these findings are believed to be unreliable since very high quantities (30 mL) and concentrations (2000 mg/mL) of the extracts were reported to have been used, and MIC values were not determined.[31] Another study reported that aqueous and methanolic whole plant extracts (50 µg/mL) of *Desmodium trifloral* Linn. inhibit *E. coli* and *S. aureus* growth on agar (ZOIs = 9-14 mm), although MIC values were also not reported.[32] Furthermore, acetone, dichloromethane, ethyl acetate and methanol *Dichrostachys cinerea* W. & A. leaf extracts had good antibacterial activity against *K. pneumoniae* and *Shigella boydii* (MIC values 40-630 µg/mL).[33] Unfortunately, all these studies were preliminary examinations only and substantially more work is required to quantify the antibacterial activity of the extracts, as well as to identify the bioactive components, as well as to determine the antibacterial mechanism(s).

Dioscorea bulbifera Linn. and related species

Notably, several *Dioscorea* spp. are used in Ayurveda to treat GI problems, including bacterial infections. Methanolic extracts prepared from the bulbils of *Dioscorea bulbifera* exert strong antibacterial activities against *E. coli* and *K. pneumoniae*, with MIC values ranging from 64-128 µg/mL, and MBC values of 128-256 µg/mL.[34] Similarly, methanolic extracts prepared from the tubers of *Dioscorea pentaphylla* Linn. inhibit *S. flexneri, S. typhi* and *V. cholerae* growth in agar well diffusion assays (ZOIs = 11-12 mm).[35] The MIC was determined to be 100 µg/mL in that study, validating the use of this species in Ayurveda, and highlighting its potential for drug development studies.

Diospyros peregrina Gurke

Diospyros peregrina fruit are used to treat diarrhoea, dysentery and cholera in Ayurvedic medicine.[1] Interestingly, methanolic *D. peregrina*. fruit extracts inhibit *E. coli, S. sonnei, Shigella dysenteriae, S. flexneri, S. boydii* and *S. aureus* growth on agar disc diffusion (ZOIs = 7-12 mm) at 200 µg/mL.[36] The authors of that study also used liquid dilution assays to quantify the antibacterial activity and reported MIC values for *E. coli, Shigella* strains and *S. aureus* of 10, 200, and 100 µg/mL, respectively.[36] These MIC values are noteworthy and highlight this species for further studies to identify the bioactive compounds, and to examine the antibacterial mechanism(s).

Eclipta prostrata Linn.

A paste made from crushed *Eclipta prostrata* (commonly known as bhringraj, ink plant) leaves is used traditionally to treat diarrhoea.[1] Despite this, relatively few studies have examined the antibacterial properties of this species, and those that did, screened the extracts against relatively few bacterial pathogens. Substantially more work is required to fully evaluate this species against a broad panel of bacterial GI pathogens. One study reported that fractions isolated from an *E. prostrata* ethanol leaf extract inhibited *S. typhi* growth in agar disc diffusion assays (ZOIs = 13-16 mm) and produced MIC values as low as 20-30 µg/mL in liquid dilution studies [37]. Another study tested a hexane extract prepared using aerial parts of *E. prostrata* and reported noteworthy inhibition of *B. cereus, E. coli, K. pneumoniae, S. aureus* and *S. typhi* growth on agar (ZOIs = 11-14mm) at 50 µL per well, with subsequent experiments revealing MIC values of 90-300 µg/mL.[38] Notably, the good activity reported in the hexane extract indicates that at least some noteworthy antibacterial components are nonpolar in nature.

Emblica officinalis Gaertn.

Emblica officinalis (synonym *Phyllanthus emblica* Linn., common name amla) is one of the most widely used plants in Ayurveda, and is a component in the common therapy, triphala.[1] Notably, previous studies have reported noteworthy activity for extracts prepared from the fruit against several bacterial pathogens.[49,70] Furthermore, the *E. officinalis* components were reported to substantially potentiate the activity of the other triphala components.[49] It is possible that the fruit extracts may contain compounds that block bacterial antibiotic resistance mechanisms, thereby potentiating the effects of the other components, although this remains to be verified.[49] Similarly, another study reported that *E. officinalis* methanolic fruit extracts also inhibit the growth of *B.*

cereus and *E. coli* in agar well diffusion assays (ZOIs = 8-12 mm) at a concentration of 50 mg/mL.[39] However, the high MIC value reported in that study would generally be classified as inactive, and therefore that report is dubious and the activity against those bacterial species should be reevaluated in more rigorous studies. Additionally, aqueous, acetone and ethanol *E. officinalis* fruits extracts inhibit *E. coli* and *S. aureus* growth in agar well diffusion assays (ZOIs = 8-10 mm) at different dilutions.[40] However, the MIC values were not reported in that study and further studies are required to quantify the potency of the extracts.

Euphorbia hirta Linn.

Euphorbia hirta is used in Ayurveda to treat multiple conditions, although it is perhaps best known for the treatment of asthma and bronchitis, diarrhoea and dysentery, eye infections, gastrointestinal parasites, and fungal skin infections.[1] Notably, several of these conditions are caused by bacterial infections and studies to verify the antibacterial activity of *E. hirta* extracts are warranted, although this species is yet to be tested against many pathogens. One study reported that ethanolic leaf extracts of *E. hirta* inhibited the growth of *E. coli* and *S. aureus* in a concentration-dependent manner, with ZOIs of 6-10 mm on agar well diffusion assay and high MIC values of 59 mg/mL and 22.5 mg/mL respectively.[41] The MIC determination was unconventional, as it was not performed using the standard liquid microdilution method. Instead, it was calculated by plotting the natural logarithm of extract concentrations against the square of inhibition zones, with the antilogarithm of the intercept providing the MIC values. This approach may lack precision compared to standard microdilution techniques. Furthermore, most assay methods define MIC values above 10 mg/mL to be inactive, and therefore these results indicate that the extracts have very low antibacterial activities (or are inactive). Further studies are required to evaluate the traditional uses of *E. hirta* extracts against bacterial pathogens causing diarrheal disease.

Ficus religiosa Linn.

Ficus religiosa is used in Ayurveda to treat coughs and colds, skin infections, nausea, vomiting and diarrhoea, although relatively few laboratory studies have verified the efficacy of this species.[1] The antibacterial activities of *F. religiosa* ethanol and methanol fruit extracts against *B. cereus* and *E. coli* were tested using agar well diffusion assays and ZOI values of 12-14 mm were reported using 80 µL of 50 mg/mL extracts.[42] However, the potency was not evaluated through MIC determination and further studies are required to benchmark the activity of this species against other plants. Furthermore, substantially more studies are required to expand the panel of bacteria that the extracts have been screened against.

Ocimum tenuiflorum Linn.

Ocimum tenuiflorum Linn. (commonly known as Tulsi in Ayurveda) characterises the holistic approach that Ayurveda takes to medicine. Indeed, this species is used to treat a very broad range of conditions, including many diseases caused by bacterial infections.[1] Despite this, relatively few reports have rigorously examined the antibacterial activity of this species, and those studies have generally not screened against antibiotic-resistant bacterial strains. For example, one study tested acetone and methanol *O. tenuiflorum* leaf extracts against *E. coli, K. pneumoniae* and *S. aureus* and reported minor growth inhibition (ZOIs = 5-8 mm) on agar when 100 µL of extracts are added to wells, although MIC values were not reported.[43] Substantially more research is required to evaluate the antibacterial potential of this species.

Phyllanthus niruri Linn.

The whole of the *Phyllanthus niruri* plant has traditional therapeutic applications. Its use in Ayurveda has been particularly well documented in the treatment of bronchitis and asthma, leprosy, anaemia and urinary discharge.[1] Whilst some rudimentary studies have reported antibacterial activity for this species, substantially more research is needed. High concentrations (100 mg/mL) of *Phyllanthus niruri* methanolic leaf extracts inhibit the growth of *B. cereus* and *S. aureus*, producing ZOI values of 14 to 15 mm, with MIC values of 3.13 and 6.25 mg/mL respectively, against these bacteria.[44] However, that study was limited with regards to the species screened, and only antibiotic-susceptible strains were tested. Furthermore, the MIC values reported in that study indicate low to moderate activity.

Our team recently tested the antibacterial potential of *Phyllanthus niruri* leaf extracts using disc diffusion and microdilution assays. The extracts showed significant activity against *S. aureus*, MRSA, *K. pneumoniae*, and *B. cereus* (MIC: 184-738 µg/mL), with the methanolic extract demonstrating stronger effects against *B. cereus*.[71] Liquid chromatography-mass spectrometry (LC-MS) analysis identified flavonoids and tannins, which may contribute to the observed activity. Additionally, additive interactions were noted when combined with some antibiotics. Initial toxicity evaluation indicated the extracts were non-toxic, supporting their potential for further antibiotic development.

Swertia chirayita (Roxb. ex-Fleming) H. Karst

Swertia chirayita (commonly known as Indian gentian) is described in Ayurveda as having a bitter taste and cooling properties. It is used as an antipyretic and laxative, as well as being used to treat gastrointestinal parasite infections, as well as some bacterial infections.[1] Notably, evaluation of the antibacterial properties of this species are relatively rudimentary. One study tested *S. chirayita* (methanolic leaf, root, and stem extracts against *K. pneumoniae, S. aureus* and *S. enterica* in disc diffusion assays

and reported substantial growth inhibition (ZOIs = 9.5-17.5 mm and 8-13.5 mm at 50 µL per agar well, respectively).[45] Inhibition in broth was not assessed, and MIC values were not reported in that study. Substantially more research is required into the antibacterial properties of this species.

Solanum nigrum Linn.

Solanum nigrum (commonly known as black nightshade) is used traditionally to treat fever, liver and metabolic conditions, vitiligo, nausea, headache and oral infections.[1] Relatively few studies have rigorously evaluated the antibacterial activity of this plant. One study reported that methanolic and aqueous *S. nigrum* fruit extracts inhibit the growth of *E. coli, S. aureus* and *S. typhi* in disc diffusion assays (ZOIs = 14-16 mm) at extract concentrations of 20 mg/mL, although MIC values were not calculated.[46] The range of bacteria tested to date is narrow and we were unable to find studies that tested extracts of this species against antibiotic-resistant bacterial strains.

Tephrosia purpurea Linn. Pers

Tephrosia purpurea (commonly known as Sharapunkha in Ayurveda) is used to treat cirrhosis, as well as some bacterial infections.[72] However, relatively few studies have reported the antibacterial activity of this species against bacterial pathogens relevant to human health. One study reported that methanolic *T. purpurea* root extracts showed mild antibacterial activity at concentrations of 100 µg/mL against *S. aureus* and *S. typhimurium* (ZOIs = 8-9 mm).[47] Whilst quantitative assays were not conducted in this study, the relatively small ZOIs measured when a high dose was tested indicates that the extracts have low activity or are ineffective. Substantially more research is required for a more complete understanding of the potential of this species to treat bacterial infections.

Terminalia species

Several *Terminalia* species are integral to traditional medicine across different cultures (particularly in Ayurveda), where they have long been used for managing bacterial infections.[1,73] Compared to the other plant species discussed in this review, the Indian *Terminalia* spp. have been relatively well reported. Aqueous and methanolic fruit extracts of *Terminalia bellirica* (Gaertn) Roxb. possess strong activity towards *E. coli*, S. *aureus, S. typhi* and *S. typhimurium* (ZOIs = 16-30 mm) when 4 mg quantities of extracts are applied to discs on agar.[48] The authors of that study also used broth microdilution assays and reported MIC values ranging from 250 to 1200 µg/mL. The findings from other studies support these results against the same bacterial species using agar diffusion assays (ZOIs of 9-18 mm), as well as against *B. cereus, S. sonnei, S. aureus* and *S. flexneri*,[49] with MIC values of 250-750 µg/mL. Substantial growth inhibition was also observed in agar diffusion assays for *Terminalia chebula* Retz. ethanolic fruit extracts when tested at with 0.5 mg of extract per disc against *E. coli, K. pneumoniae, S. aureus* and *S. typhi*, with broth assays yielding MIC values ranging from 48-968 µg/mL.[50] The water and methanolic fruit extracts of *T. chebula* inhibit bacterial growth on agar (ZOIs = 13-20 mm) against *B. cereus, S. sonnei, S. typhimurium, S. aureus* and *S. flexneri,* with MICs values of 250-750µg/mL.[49]

Notably, *Terminalia chebula* extracts potentiate the activity of other species, such as *Terminalia bellirica* and *Emblica officinalis*, further explaining the preference for using triphala over its individual components. Triphala is a traditional Ayurvedic formulation consisting of *Terminalia chebula, Terminalia bellirica*, and *Emblica officinalis*, known for its antimicrobial, antioxidant, digestive, and immune-boosting properties. Whilst each individual plant component of triphala inhibits the growth of various pathogenic bacteria, their combined use enhances this effect.[49] The traditional combination of these three plants not only broadens the antimicrobial spectrum, but also significantly amplifies bacterial inhibition, making triphala substantially more effective than its individual components. Whilst Indian *Terminalia* species are well studied, further research is needed to explore their potential in combination with other extracts or antibiotics to combat antimicrobial resistance.

Tinospora cordifolia (Willd.) Miers ex Hook. f. & Thoms.

Tinospora cordifolia (Willd.) Miers ex Hook. f. & Thoms. (commonly known as Guduchi) is a herbaceous vine of the family Menispermaceae that is used in Ayurveda to treat multiple conditions, including skin infections, diabetes, jaundice gout.[1] Several of these diseases are caused by bacterial infections, yet relatively few studies have evaluated this species for antibacterial activity. One study evaluated the growth inhibitory activity of acetone, water, ethanol and ethyl acetate stem extracts of *T. cordifolia* against *K. pneumoniae* growth on agar and reported noteworthy growth inhibition in disc diffusion assays (ZOIs = 10-12 mm) at 20µL extract/disc, with an MBC value of 1.29 mg/mL.[51] In contrast, only acetone and ethyl acetate stem extract inhibited *E. coli* growth in a different study (ZOIs = 19-26 mm). However, both of those studies screened against single bacterial pathogens, and neither quantified the MIC. Furthermore, both studies only tested against antibiotic sensitive strains. Substantially more research is required to evaluate the antibacterial potential of this species.

Phytochemistry

Antioxidants

An imbalance of prooxidants/antioxidants in the gastrointestinal system can induce an increase in oxidative stress, which is linked to several gastrointestinal (GI) problems, including diarrhoea.[74] Reactive oxygen species (ROS) are formed during bacterial GI infections as an important immunological response, and this

ROS depletes the levels of glutathione (the primary antioxidant of intestinal epithelial cells). Glutathione peroxidase catalyses the oxidation of reduced glutathione (GSH) to glutathione disulphide (GSSG), which subsequently reduces H_2O_2 to H_2O, and lipid hydroperoxides to stable alcohols. Antioxidants are therefore critical to maintaining a healthy environment in the gastrointestinal system and several studies have correlated the high antioxidant capacity of some Ayurvedic medicinal plants with their therapeutic properties.

Multiple studies have quantified the antioxidant activities of plants used to treat gastrointestinal illness in Ayurveda. In some cases, these studies have also identified compounds that contribute to these antioxidant activities. For example, three new diterpenoid alkaloids 6β-methoxy, 9β-dihydroxylheteratisine, 1α,11,13β-trihydroxylhetisine, 6,15β-dihydroxylhetisine, as well as the previously identified compounds iso-atisine, hetisinone, heteratisine, 19-epiisoatisine and atidine, were isolated from an 80% methanolic extract prepared from the aerial parts of *A. heterophyllum*.[75] All these compounds demonstrated good antioxidant and cholinesterase inhibition activities, with 1α,11,13β-trihydroxylhetisine and hetisinone producing significantly higher DPPH (1,1-diphenyl-2-picrylhydrazyl) free radical scavenging activity compared to the other extract compounds.[75] Similarly, leaf extracts of *A. nilotica* also have high antioxidant activity, with DPPH inhibition values of 92% at 1 mg/mL.[6] The authors of that study also reported substantial antioxidant activity (88.5% and 33%) for extracts prepared from the pods and bark respectively.[6] Total flavonoid content (TFC) and total phenolic content (TPC) of the *A. nilotica* leaf and pod extracts were also high, confirming that *A. nilotica* leaf extracts contain high levels of antioxidant compounds. The IC_{50} of the leaf and pod extracts were 360 and 422 µg/mL, which was comparable to the positive control L-ascorbic acid (IC_{50} = 305.6 µg/mL).

In another study, a 50% ethanol *A. aspera* leaf extract showed substantial total antioxidant activity and reducing power, with IC_{50} values of 62 µg/mL measured for DPPH free radical scavenging, and 68 µg/mL for hydroxyl scavenging activity.[8] Another study also reported dose-dependent DPPH activity for methanolic and aqueous *A. aspera* leaf extracts and linked that activity with the high levels of phenolic compounds in the extracts.[76] A different study reported TPC, TFC and antioxidant activities of 209 µg gallic acid (GA)/mg, 17.5 µg quercetin (QE)/mg, and 25.1% (100 µg/mL) respectively for a methanolic *A. aspera* whole plant extract.[77] Similarly, the DPPH free radical scavenging activity of *A. indica* methanolic leaf extracts was reported to be 71.2% using 50 µL of a 10 mg/mL extract. In that study, the methanolic leaf extract was reported to contain 86 mg/g of total phenols (as gallic acid equivalent), 105 mg/g of flavonoids (as rutin equivalent), and 65.3 mg/g of proanthocyanidins (as rutin equivalent).[78]

Acetone, chloroform and ethanol extracts prepared using *B. variegata* leaves were reported to have good reducing power (absorbance 1.42, 0.89 and 0.59 respectively), when tested at a concentration of 3.3 mg/mL.[11] Similarly, methanolic *B. diffusa* leaf extracts also have good antioxidant activity, with maximum total phenolic, total flavonoid and ascorbic acid contents of 24.5 mg GAE/gDW (dry weight), 79.86 mg QE/gDW and 0.3 mg/gDW, respectively.[79] The authors of that study reported that a stem extract of *B. diffusa* had the highest free radical scavenging activity of all plant parts studied, with an IC_{50} value of 90.8 µg/mL. In a different study, the antioxidant DPPH radical scavenging activity of a methanolic *B. diffusa* extract (IC_{50} < 250 µg/mL) was reported to be higher than that of the ethanolic (IC_{50} = 250 µg/mL) and aqueous (IC_{50} > 250 µg/mL) extracts.[80]

Another study reported that methanolic *Berberis lyceum* root extracts had similar DPPH free radical scavenging activity as an ascorbic acid control, with 79.6% inhibition noted at 1000 µg/mL, and an IC_{50} value of 110 µg/mL.[81] HPLC analysis of the *B. lyceum* methanolic root extracts resulted in the identification of six phenolic compounds, including quercetin, chlorogenic acid, berberine, rutin, mandellic acid and hydroxy benzoic acid.[81] The presence of berberine and chlorogenic acid in the extract is noteworthy and the authors highlighted these compounds for their high antioxidant activity.

Another study examined 30% ethanol seed extracts of *Brassica juncea* and reported that they had substantially higher antioxidant activity than aqueous extracts prepared from the same seed material (DPPH IC_{50} values of 0.17 and 0.39 mg extract/mL, respectively).[14] The authors of that study reported that flavonoids were substantially more abundant in the ethanol extract compared to the aqueous extract, whilst the aqueous extract was more abundant in alkaloids and other polyphenolic compounds. Notably, another study reported that sinapic acid (3,5-dimethoxy-4-hydroxycinnamic acid) isolated from *B. juncea* methanolic leaf extracts had considerable antioxidant activity.[82] The authors also reported that this compound scavenges peroxynitrite ($ONOO^-$), a potent cytotoxic agent that causes considerable oxidative damage to proteins, lipids and DNA.[82] Furthermore, the same study determined that sinapic acid inhibits nitration of bovine serum albumin and low-density lipoprotein (LDL) in a dose-dependent manner.[82] Another study identified isorhamnetin 3,7-di-*O*-*β*-D-glucopyranoside (isorhamnetin diglucoside) as a major flavonoid antioxidant in methanolic *B. juncea* leaf extract.[83] Of further note, oral administration of isorhamnetin diglucoside (10 or 20 mg/kg of body weight/day for 10 days) in streptozotocin-induced diabetic rats significantly reduced serum levels of glucose and 5-hydroxymethyl furfural (5-HMF), an indicator of oxidative stress.[83]

A methanolic flower extract of *Butea monosperma*, as well as ethyl acetate and butanol fractions derived from this extract, have strong free radical scavenging activity due to their high phenolic content (16.1, 25.3 and 17.7% (w/w) in the extract, and in the ethyl acetate and butanol fractions respectively).[84] Another study

used DPPH assays to examine the antioxidant activity of a *B. ceida* methanol flower extract (95.4%).[16] Furthermore, *B. ceida* methanolic stem bark extract was reported to contain phenolic and flavonoid contents of 133 µg GAE/mg and 998 µg QE/mg, respectively.[17] These extracts had considerable anti-radical activity, with EC_{50} values of 18.8, 23.6 and 139.4 µg/mL in nitric oxide, DPPH and reducing power assays, respectively.[17]

DPPH assays were also used to evaluate the radical scavenging activity for *Cassia fistula* 90% ethanolic leaf and 90% methanolic stem bark extracts, as well as pulp and flower extracts.[85] The percentage inhibition was high in the stem bark (93%) and leaf extracts (75%), although it was substantially lower in the flower (33%) and pulp extracts (16%). The authors postulated that this may be due to the presence of the compound chrysophanol and reducing sugars in the flower and pulp extracts at relatively high concentrations.[85] Another study reported that the free radical scavenging activity of hydro-alcoholic *C. fistula* seed extracts was 68% at 60 µg/mL extracts.[86]

Considerable antioxidant activity has also been reported for multiple other plants used in Ayurveda to treat gastrointestinal infections. Indeed, methanolic *Cannabis sativa* leaf extracts, which contain an abundance of phenolic compounds (36.4 GAE/g) and flavonoids (59 QE/g), inhibit DPPH by 49.5%.[87] A different study reported that aqueous *C. sativum* leaf and stem extracts have higher phenolic contents (189 mg caffeic acid equivalents/100 g extract, and 117 mg caffeic acid equivalents/100 g extract) compared to methanolic leaf and stem extracts (110 mg caffeic acid equivalents/100 g extract and 63 mg caffeic acid equivalents/100 g extract).[88] Interestingly, all the extracts exhibited higher hydroxyl radical-scavenging activity than the ascorbic acid standard. The reducing power of a *Celosia argentea* ethyl acetate leaf extract far exceeded (289.2 mg ascorbic acid (AA)/g) that of the methanolic extract (181.5 mg AA/g),[89] although, the methanolic extract (70.4 %) had substantially greater DPPH free radical scavenging activity than the corresponding ethyl acetate leaf extract (9.8%).[89] Additionally, methanolic and water *Cissampelos pareira* leaf extracts showed considerable free radical scavenging activities (36% and 34%, respectively) at 100 µg/mL.[23] Furthermore, another study reported that a *Cinnamonium tamala* petroleum ether leaf extract exhibited 66% antioxidant activity in a β-carotene linoleate model system (which was comparable to the 84% evaluated for the butylated hydroxyanisole standard (84%)).[90] Another study reported high higher antioxidant capacities for an ethanolic leaf and bark extracts prepared from the related species, *Cinnanomium zeylanicum* compared to dichloromethane:methanol extracts tested in parallel.[91] The authors also reported that the ethanolic leaf extracts contained substantially higher total phenolic (44.5 mg GA/g) and flavonoid (12 mg QE/g) contents than the bark extracts. Interestingly, despite this, the bark extract had substantially greater DPPH radical scavenging activities (108 mg Trolox equivalents/g) than the leaf extract.[91]

Additionally, another study reported total polyphenol contents of 153 mg GAE/g and 190 mg GAE/g, for aqueous and methanolic *Dalbergia sissoo* stem bark extracts, respectively.[92] The authors of that study reported flavonoid contents of the aqueous and methanolic extracts of 45.3 mg QE/g and 49.41 mg QE/g, respectively.[92] Notably, the aqueous *D. sissoo* stem bark extract had a higher free radical scavenging activity than the methanol extract, with IC_{50} values of 12.2 µg/mL and 23.6 µg/mL respectively.[92] Another study reported dose-dependent antioxidant activity for a hydroalcoholic extract of *Desmostachya bipinnata*, with an IC_{50} value of 264 µg/mL quantified in H_2O_2 scavenging assays.[93] Furthermore, the authors reported that the extract prevented oxidative DNA damage in the presence of a DNA damaging agent (Fenton's reagent) at a concentration of 50 µg/mL.

Another study calculated the total phenolic and flavonoid content of ethanolic *Desmodium gangeticum* leaf extracts to be 16.2 mg/mL (gallic acid equivalents) and 10.5 mg/mL (catechol equivalents), respectively.[94] The authors of that study also reported concentration dependent DPPH radical scavenging activity for the ethanolic leaf extract of in that study.[94] An ethyl acetate fraction produced from the methanolic extract (whole plant) of the related species *Desmodium triflorum* had substantial DPPH and Trolox-equivalent antioxidant capacity (TEAC).[95] The authors determined that 0.4 mg of the ethyl acetate fraction had equivalent radical scavenging activity to the standard antioxidants α-tocopherol and Trolox (186.6 µg and 82.5 µg respectively). The total phenolic and flavonoid contents of the crude methanolic extract were equivalent to 36.6 mg catechin and 45.6 mg rutin/g, respectively. In a separate study, an ethyl acetate fraction of a *D. cinerea* aqueous-ethanol root extract was reported to contain high phenolic and flavonoid contents (158 mg GAE/g and 32 mg rutin equivalent/g respectively).[96] The authors of that study also reported that the *D. cinerea* extract and its ethyl acetate fraction showed good DPPH radical scavenging activity (IC_{50} value of 8 µg/mL and 6.7 µg/mL respectively), which was reported to be comparable to the reference compound curcumin.[96]

Ethanol and aqueous *Dioscorea bulbifera* bulbil extracts were evaluated for radical scavenging activity in DPPH assays, with IC_{50} values of 34.2 and 13.2 µM reported respectively.[97] The authors also isolated the flavonoid compounds myricetin, quercetin, (+)-catechin and 3,5-dimethoxyquercetin from fractions produced from an ethanolic extract and reported good free radical scavenging potential (IC_{50} values of 4.8, 5.3, 8.3 and 9 µM respectively), which were comparable to the scavenging activity of ascorbic acid reported in that study (IC_{50} = 4 µM).[97] Nuclear magnetic resonance (NMR) analysis of an active fraction of the extract revealed the secondary metabolite diosgenin, which is responsible for antibacterial and antioxidant activities of that

extract. Another study evaluated the antioxidant capacity of the related species *Dioscorea pentaphylla*. That study reported that an *D. pentaphylla* acetone tuber extract showed better antioxidant activity (89 µg/mL EC_{50} values for DPPH, and 86 µg/mL EC_{50} values for metal chelating activity) than a methanolic extract produced from the same plant material (82 µg/mL EC_{50} values for DPPH, and 81 µg/mL EC_{50} values for metal chelating activity).[35]

Substantial antioxidant activity has been reported for a methanolic fruit extract of *Diospyros peregrina* in type-1 diabetic rats[98] where the activities of superoxide dismutase (SOD), catalase (CAT), and glutathione (GSH) were increased in extract-treated diabetic rats in specific tissues. Interestingly, lipid peroxidation was reduced almost to normal levels in extract-treated groups, and the effective dose of the extract was determined to be 300 mg/kg body weight, which is comparable to the effective dose of glibenclamide.[98] Another study reported that an ethanolic *Eclipta prostrata* leaf extracts have substantial antioxidant activity (77% inhibition at 500 g/mL), similar to that of tocopherol (80% inhibition).[37]

Another study examined the antioxidant activities of *Emblica officinalis* fruit extracts and reported IC_{50} values of 1.4, 382, 13.8, 33.9 and 830 µg/mL, respectively in DPPH, hydroxyl, superoxide, nitric oxide and peroxynitrite free radical scavenging assays respectively.[99] The same study reported phenolic, flavonoid, and ascorbic acid contents of the fruit extracts to be 215.6 mg/mL GAE/100 mg, 176 mg/mL QE/100 mg, and 71 mg/mL for ascorbic acid/100 mg, indicating considerable antioxidant activity. Seven phenolic compounds were isolated from *E. officinalis* 60% acetone extracts in another study, including mucic acid 1-ethyl ester 3-*O*-gallate, mucic acid 6-methyl ester 3-*O*-gallate, and mucic acid 6-ethyl ester 2-*O*-gallate, mucic acid 1,6-dimethyl ester 2-*O*-gallate, mucic acid 1-methyl ester 2-*O*-gallate, mucic acid 1,4-lactone methyl ester 5-*O*-gallate, and mucic acid 6-methyl ester 2-*O*-gallate [100]. All compounds exhibited potent antioxidant potential (DPPH: IC_{50} 7.5-13.2 µM; ABTS: 1.1-2.8 µM Trolox/µM; FRAP:1.1-2.3 µM Fe^{2+}/µM), which was comparable to the reference compound α-tocopherol included in that study.[100]

Methanolic leaf extracts of *Euphorbia hirta* were reported to have a DPPH radical scavenging activity of 73%, which is comparable to butylated hydroxytoluene (BHT).[101] The authors of that study also reported substantial scavenging activity for the flowers (52%), roots (48.5%) and stems (44%) of this species, with the IC_{50} values of 0.8, 0.97, 0.98, 1.36 and 0.79 mg/mL measured for leaf, flower, root and stem extracts, as well as a BHT control, respectively.[101] Furthermore, the same study reported high total phenolic (206 mg GAE/g) and flavonoid contents (38 mg CEQ/g) for *E. hirta* leaf extracts, as well as concentration-dependent reducing power, which was comparable to that of ascorbic acid.[101]

Ethanolic and methanolic *Ficus religiosa* fruit extracts have been reported to have good ferric reducing antioxidant power (FRAP) of 194-197µg BHT/mg, as well as strong DPPH radical scavenging activities (94% and 91%, for ethanolic and methanolic extracts respectively).[42] Furthermore, the total phenolic and flavonoid contents of both extracts were similar in the fruit extracts (7-10 µg GAE/mg and 42-43 µg CE/mg, respectively). A different study also reported high phenolic and flavonoid contents for methanolic extracts prepared from the leaves of this species (235 µg GAE/mg and 93 mg CE/mL).[102] Similarly, another study evaluated the antioxidant activity of 50% methanolic leaf extracts of another plant, *Ocimum tenuiflorum*. The authors of that study reported antioxidant activity similar to that of ascorbic acid, with EC_{50} values of 10, 7.3, and 5.3 g/mL for DPPH, superoxide, hydroxyl, and ABTS radicals respectively.[103] Additionally, the flavonoid and phenolic contents of the extract were reported to be 222 mg QE/g and 87 mg GAE/g.[103]

Treatment of diabetic male rats with *Phyllanthus niruri* aqueous leaf extracts (200 and 400 mg/kg) reduces lipid peroxidation and malondialdehyde (oxidative stress marker) levels.[104] The authors of that study reported that the leaf extracts had substantial DPPH, hydroxy radical, superoxide radical and hydrogen peroxide scavenging activities (IC_{50} = 90, 100, 94 and 132 µg/mL, respectively). A different study evaluated the antioxidant activities of an aqueous root extracts of a different species, *Tephrosia purpurea,* and reported IC_{50} values of 78 and 89 µg/mL respectively.[105]

Several *Terminalia* species are important in Ayurveda, and those plants have been relatively well studied. Indeed, one study compared the properties of 70% methanolic extracts prepared using *Terminalia bellirica* and *Terminalia chebula* fruit.[99] Notably, the *T. bellirica* fruit extract had high phenolic contents (133 mg/mL GAE/100mg extract) and IC_{50} values of 1.4, 203, 18, and 40.8 µg/mL for DPPH, hydroxyl, superoxide, and nitric oxide radicals, respectively.[99] In contrast, the 70% methanolic *T. chebula* fruit extract had a higher flavonoid content (219 mg/mL QE/100mg extract) and stronger free radical scavenging capabilities for singlet oxygen and hypochlorous acid (IC_{50} = 233 and 271µg/mL, respectively).

The antioxidant activity of an aqueous *Tinospora cordifolia* leaf extract was also evaluated, and a high DPPH radical scavenging activity was calculated, which was substantially higher than that of a corresponding aqueous stem extract.[106] Ethanolic whole plant extracts of *Swertia chirayita* were tested and reported to be rich in phenolics (243 mg GAE/g extract), although they were low in flavonoids (5 mg RU/g extract).[107] In addition, the authors of that study reported that these extracts displayed noteworthy DPPH inhibition (IC_{50} = 268 µg/mL) and ABTS scavenging activity (IC_{50} = 6.5 µg/mL). Furthermore, another study reported that chloroform extracts prepared from *Solanum nigrum* leaves and fruit contain higher phenolic contents compared with acetone and methanol extracts prepared from the same plant material.[108] Interestingly, that study reported that despite the differences in

phenolic contents, the extracts had similar DPPH inhibition levels (IC_{50} = 50 µg/mL).[108]

Alkaloids

Alkaloids are organic compounds that contain at least one nitrogen atom in their structure. They have a wide range of structural diversity and a corresponding wide range of pharmacological activities. Several notable alkaloids have been identified in the Ayurvedic plants used to treat gastrointestinal infections. *Aconitum heterophyllum* is particularly rich in alkaloids. Atisine, hetisine, heteratisine and benzoyl-heteratisine are the major alkaloids that have been identified in the roots *A. heterophyllum*.[109] Seven diterpene alkaloids have also been identified in similar extracts, including heterophyllisine, heterophylline, heterophylline, atidine, F-dihyroatisine, hetidine and hetisinone.[110] Other additional diterpenoid alkaloids identified in *A. heterophyllum* root extracts includes heterophyllinine-A and heterophyllinine-B, dihydroatisine and lycoctonine.[111] Two additional aconitine-type norditerpenoid alkaloids (6-dehydroacetylsepaconitine, 13-hydroxylappaconitine), and three norditerpenoid alkaloids (lycoctonine, lappaconitine, delphatine) have also been identified.[112] Notably, 6-dehydroacetylsepaconitine and 13-hydroxylappaconitine have antibacterial activity against *S. aureus* and *S. typhi* in agar diffusion assays, whilst lycoctonine, lappaconitine and delphatine each inhibit the growth of *S. typhi*.[112]

Several noteworthy isoquinoline alkaloids, including magnoflorine, magnocurarine, cissamine, curine, hayatinine, salutaridine, pareirarine, and cycleanine have been identified in *Cissampelos pareira* extracts.[66,113] Other studies have identified multiple alkaloid components in *Desmodium triflorum* whole plant extracts, including N, N-dimethyl-tryptophan, hypaphorine, choline, hypaphorine, indole-3-acetic acid, bufotenine N-oxide, tyramine, stachydrine, hordenine, 3,4-dihydroxyphenethyltrimethyl ammonium hydroxide and trigonelline.[114,115] Additionally, indole-3-alkylamine, β-carboline, and tetrahydro-β-carboline have been extracted from various parts of the related species *Desmodium pulchellum*.[114,116] However, none of those studies tested the prokaryote growth inhibitory properties of these compounds and substantially more research is needed to investigate their antibacterial capabilities and potencies. The alkaloids tinosporine, tembeterine, magnoflorine, berberine, choline, jatrorrhizine, palmatine and isocolumbin have been identified in relative abundance in *Tinospora cordifolia*.[117]

Additionally, steroidal alkaloids, including solanine A, 7*α*-OH khasianine, 7α-OH solamargine, 7α-OH solasonine, solasodine, khasianine, β_2-solasonine, solasonine, solamargine, and 12*β*, 27-dihydroxy solasodine, have been isolated from methanolic *Solanum nigrum* fruit extracts.[118] In a different study, three additional steroidal alkaloid glycosides ((25R)-22αN-4-nor-spirosol-5(6)-en-3β-ol-6-al-3-O-α-L-rhamnopyranosyl-(1 → 2)-[α-L-rhamnopyranosyl-(1 → 4)]-β-d- glucopyranoside, (25R)-22αN-spirosol-5(6)-en-3β-ol-7-oxo-3-O-α-L-rhamnopyranosyl-(1 → 2)-[α-l-rhamnopyranosyl-(1 → 4)]-β-d-glucopyranoside, and (25R)-22αN-spirosol-4(5)-en-3β-ol-6- oxo-3-O-α-L-rhamnopyranosyl-(1 → 2)-[α-L-rhamnopyranosyl-(1→4)]-β-D- glucopyranoside) were identified in a 70% methanolic immature fruit extracts of *S. nigrum*.[119] However, the antibacterial properties of these molecules have not yet been explored, and substantially more research is required.

Flavonoids and Phenolic Acids

Figures 1 and 2 show the chemical structures of flavonoids identified in the medicinal plants studied, including luteolin (Figure 1a), luteolin-7-*O*-glucoside (Figure 1b), quercetin -3-glucopyranoside, (Figure 1c), quercetin-3-glu-(6-1)-rha (Figure 1d), 4-methoxy quercetin -7-O-glycoside (Figure 1e), rutin (Figure 1f), apigenin (Figure 1g), 5,3,4-trihydroxy-6-methoxy-7-O-a-L-rhamnopyranosyl-(1→2)-O-b-D-galactoprranoside (Figure 1h), pinocembrin (Figure 1i), kaempferol (Figure 1j), afzelin (Figure 1k), quercitrin (Figure 1l), myritrin (Figure 1m), diosmetin (Figure 1n), chrysoeriol (Figure 1o), vitexin (Figure 1p), genistein-7-*O*-glucoside (Figure 1q) and epicatechin (Figure 2a), wedelolactone (Figure 2b), butein (Figure 2c), clovamide (Figure 2d), hydroxymethylfurfural (Figure 2e), cinnamic acid (Figure 2f), ferrulic acid (Figure 2g), p-coumaric acid (Figure 2h), caffeic acid (Figure 2i), eugenol (Figure 2j), phloroglucinol (Figure 2k), scopoletin (Figure 2l), lanceolatin (Figure 2m), karanjin (Figure 2n), pongamol (Figure 2o). These compounds, including flavones, flavonols, and flavanones, vary in their substitution patterns, which may influence their biological activities. The structural representations help highlight the diversity and potential pharmacological relevance of the flavonoids present.

Flavonoids and other polyphenolic acids are common plant compounds, with a wide range of beneficial properties often linked to their high antioxidant activity.[120] Therefore, many studies exploring the phytochemistry of Ayurvedic plants have focussed on their flavonoid and polyphenolics contents. Luteolin and luteolin-7-*O*-glucoside have been identified in 70% ethanol whole plant extracts of *Achillea millefolium*.[121] Interestingly, luteolin-7-*O*-glucoside has been reported to be a strong inhibitor of *E. coli, K. pneumoniae* and *S. typhimurium* growth, producing ZOIs 10-11 mm at 400 µg extract/disc on agar disc diffusion assay.[122] Unfortunately, that study did not quantify the activity by calculating MIC values and further studies are required. Furthermore, these compounds were tested against a limited panel of bacteria and future studies are needed to evaluate their activity spectrum against an expanded panel of pathogens.

A research study isolated two flavonoids from *Azadirachta indica* methanolic leaf extracts.[123] The authors of that study identified those compounds as genistein 7-*O*-glucoside and (-)-epicatechin. The compounds were also tested as bacterial growth inhibitors

and good antibacterial activity was reported towards *Bacillus, Lactobacillus* spp. and *E. coli* at 1000 µg/mL.[123] Notably, the MIC values of these compounds were not reported, and as the concentration tested is relatively high, the MIC values of these compounds need to be quantified in future studies to allow their activity to be benchmarked against other antibacterial drug targets. Additionally, azadirachtin A, trilinolein and octadecanoic acid-tetrahydrofuran-3,4-diyl ester were isolated from methanolic *A. indica* dried bark.[124] However, these compounds were not evaluated for antibacterial activity in that study. Another study identified quercetin-3-glucopyranoside and quercetin-3-glu (6→1) in methanolic *A. indica* leaf extracts and reported that both compounds have noteworthy antibacterial activity against *E. coli*, with MIC values of 0.78 µg/mL.[125] That study also included norfloxacin as a reference antibiotic and reported that the plant compounds had similar potency to the antibiotic control (norfloxacin MIC = 0.19 µg/mL; quercetin-3-glu (6→1) rha MICs against *K. pneumoniae* and *S. aureus* 1.5 and 6.25 µg/mL respectively; quercetin-3-glucopyranoside MIC against *K. pneumoniae* and *S. aureus* = 25 µg/mL).[125]

Four flavonoids were isolated from the whole plant ethanolic extract of *Boerhavia diffusa*: eupalitin 3-*O*-β-D-galactopyranosyl-(1′″→2″)-*O*-β-D-galactopyranoside, 3,3′,5-tri hydroxy-7-methoxyflavone, 4′,7-dihydroxy-3′-methylflavone and 3,4-dimethoxyphenyl-1-*O*-β-D-apiofuranosyl-(1″→3′)-*O*-β-D-glucopyranoside.[126] The antibacterial activities of these compounds have not been investigated.

Bioactive flavonoids have been isolated from the methanolic flower extract of *Butea monosperma*, including butein (a dihydrochalcone), monospermoside, isoliquiritigenin, 7,3',4'-trihydroxyflavone (a flavone), the four flavanones (+)-butin (1a), (−)-butrin (3a), (+)-isomonospermoside and (−)-liquiritigenin, and the three isoflavones formononetin, afrormosin and formononetin-7-*O*-β-D-glucopyranoside.[127] Butein shows strong antibacterial activity towards *Mycobacterium tuberculosis*, producing an MIC of 12.5 µg/mL, whilst the MIC values for the other flavonoids are between 25 and 100 µg/mL.[127] Seven flavonoid glucosides have been isolated from ethanolic flower extracts of *B. monosperma*, including butrin, isobutrin, coreopsin, isocoreopsin, sulphurein, monospermoside and isomonospermoside.[128] The antibacterial properties of these compounds have not been identified to date.

The flavonol *C*-glycoside, shamimin, has been isolated from the ethanolic extract of fresh undried leaves of *Bombax ceiba*.[129] Further investigation is required to determine the antibacterial potential of shamimin. Another study identified quercetin-3-O-β-D-glucopyranoside, quercetin-3-O-β-D-glucuronopyranoside, rutin, sexangularetin-3-O-sophoroside, vitexin, isovitexin, vicenin-2, kaempferol-3-O-rutinoside, and kaempferol-3-O-β-D-glucuronopyranoside in the 70% methanol flower extracts of *B. ceiba*.[130]

A bioactive flavone glycoside, 5,3,4-tri-hydroxy-6-methoxy-7-O-a-L-rhamnopyranosyl-(1→2)-O-b-D-galactopyranoside, has been isolated from the acetone fraction of defatted seed extracts of *Cassia fistula*.[131] The isolated compound has a strong inhibitory effect *E. coli, K. pneumoniae, S. pyogenes* and *S. aureus* on agar (ZOIs = 19.5, 20.5, 18.5 and 23 mm, respectively).[131] The leaves of *Cinnamomum tamala* contain the polyphenolic compounds kaempferol, quercetin, kaempferol-3-O-glucopyranoside, kaempferol-3-O-sophoroside, kaempferol 3,7 di-O-rhamnopyranoside, quercetin 3-O-rutinoside glycosidic, myricetin, and kaempferol-3-O-rhamnoside.[132]

The ethanolic leaf extract of *Dalbergia sisso* contains the flavonoids genistein, pratensein, and biochanin-A, and the isoflavone glycosides caviunin-7-O-β-D-apiofuranosyl-(1→6)-β-D-glucopyranoside, biochanin-A-7-O-[β-Dapiofuranosyl -(1-5)-β-D-apiofuranosyl-(1-6)-β-D-glucopyranoside, biochanin-A-7-O-[β-D-apiofuranosyl-(1-6)- β-D-glycopyranoside and biochanin-A 7-O-glucoside.[133] Other isoflavonoid glycosides identified from the leaf and stem bark methanolic extract of *D. sisso* include tectorigenin 7-O-[β-d-apiofuranosyl-(1→6)-β-d-glucopyranoside], prunetin 4′-O-[β-d-apiofuranosyl-(1→6)-β-d-glucopyranoside], 7-methyltectorigenin 4′-O-[β-d-apiofuranosyl-(1→6)-β-d-glucopyranoside], genistein 8-C-[β-d-glucopyranoside] and prunetin 4′-O-[β-d-glucopyranoside].[134] Other compounds, including a chalcone (2,3-dimethoxy-4′-γ, γ-dimethylallyloxy-2′-hydroxychalcone), isoflavones (7-γ,γ-dimethylallyloxy-5-hydroxy-4′-methoxyisoflavone and biochanin A), a flavone (7-hydroxy-6-methoxyflavone) and a rotenoid (dehydroamorphigenin) have been isolated from the acetone and methanolic root bark extracts of *D. sisso*.[135] Further studies are required to investigate the antibacterial properties of these molecules. The flavonoid 4`- methoxy quercetin-7-O-glucoside has been identified in the 70% methanol whole plant extracts of *Desmostachya bipinnata*,[136] which has been found to possess anti-*H. pylori* activity (MIC = 62 µg/mL).

A review article highlighted the diverse pharmacological activities of *Desmodium gangeticum*, attributing many of its therapeutic effects to its rich flavonoid content. Several flavonoids and their derivatives have been identified in the whole plant, including flavone glycosides, prenylated flavones, and flavonols.[137] Key compounds such as 4′,5,7-trihydroxy-8-prenylflavone glycoside, 8-C-prenyl-5,7,5′-trimethoxy-3′,4′-methylenedioxy flavone, rutin, quercetin-7-O-β-D-glucopyranoside, kaempferol-7-O-β-D-glucopyranoside, 5-O-methylgenistein-7-O-β-D-glucopyranoside, 4-O-alfha-L-rhamnopyranosyl-(1-6)-β-d-glucopyranoside, 4-O-alfha-L-rhamnopyranosyl-(1-6)-β-d-glucopyranosid, 4,5,7-trihydroxy-8-prenylfavones 4-O-l-rhamnopyranosyl-(1-6)-d glucopyranoside, 4,5,7 trihydroxy-8-prenylfavone 4-O-L-rhamnopyranosyl (1-6) D glycopyranoside, and β-amyrone were identified.[114,137] These

compounds, along with the pterocarpan-type flavonoids gangetin, gangetinin, desmodin, and democarpin each contribute to the plant's documented antileishmanial, antioxidant, anti-arthritic, and immunomodulatory properties.[138] Vitexin, genistin, fucosterol, and diholosylfavane and 2-glucosylvitexin have been identified in the whole plant of *Desmodium triflorum.*[114] Vitexin exhibited moderate antibacterial activity against *S. aureus* (MIC = 254 µg/mL) by altering its hydrophobicity, thereby obstructing biofilm formation.[139] Fucosterol has noteworthy efficacy against *E. coli* (MIC = 0.31 mM), comparable to the reference antibiotic neomycin (MIC = 0.41 mM).[140]

The 70% methanolic leaf extracts of *Dichrostachys cinera* contains apigenin-7-O-apiosyl (1→2) glucoside, chrysoeriol-7-O-apiosyl (1→2) glucoside, clovamide, and flavonol glycosides (quercetin-3 -O-rhamnopyranoside, quercetin-3-O-glucopyranoside, myricetin-3-O-rhamnopyranoside and myricetin-3-O-glucopyranoside).[141] Clovamide has antiviral effects against the H5N1 influenza A virus and antiparasitic effects against *Trypanosoma evansi.*[141] Ethyl acetate bark extracts of *D. cinerea* contain 7,4'-dihydroxyflavon, 7,3',4'-trihydroxyflavon, apigenin, monoglycerides of tetracosanoic and 26-hydroxyhexacosanoic acids, 3-α-L-O-rhamnopyranosyl-(2S,3R)-5,7,4′-trihydroxyflavanon and 3-α-L-O-rhamnopyranosyl-(2S,3S)-5,7,4'-trihydroxyflavanon.[142] Apigenin appears to inhibit *E. coli* growth by increasing reactive nitrogen and oxygen species, leading to bacterial apoptosis.[143] Aqueous fruit extracts of *Diospyros peregina* contain the flavonoids luteoline-4′-methyl-ether-7-*O*-glucoside and quercetin-3-*O*-(glucosyl)-glucoside.[144] Antibacterial studies have not been performed on these compounds isolated from *D. cinera* or *D. peregina*.

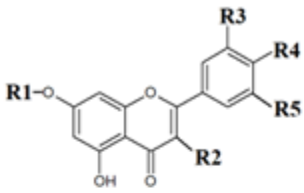
Similarly, ethanolic extracts produced from the aerial segments of *Eclipta prostrata* also contain substantial levels of flavonoids, including wedelolactone, luteolin and luteolin-7-O-glucoside.[145] Notably, luteolin and its derivatives showed promising antibacterial activity against *E. coli* and *S. aureus* with MIC values ranging from 3-50 µg/mL.[146] Further studies have demonstrated that the antibacterial properties of these compounds are due (at least in part) to inhibition of bacterial topoisomerase I and II enzymes.[147] Additionally, wedelolactone containing nanoparticles have been shown to inhibit the growth of *E. coli, K. pneumoniae* and *S. aureus* on agar (ZOIs = 10, 10 and 13 mm at 25 µg/mL), although MIC values were not reported in those studies.[148]

The major phytochemicals isolated from the ethyl acetate and butanol fractions of 75% methanolic fruit extracts of *Emblica officinalis* are ascorbic acid, rutin, quercetin and catechol.[149] Rutin decreases the MIC values of quercetin from 250 to 100 µg/mL against *S. enteritidis*, and from 350 to 200 µg/mL against *B. cereus.*[150] Interestingly, rutin does not have antibacterial activity when used alone, even at concentrations of 1000 µg/mL. Another study showed catechol derivatives I-IV have strong antibacterial activity against *E. coli* and *S. aureus*, with MIC values ranging from 5 - 25 µg/mL, comparable to the reference antibiotic tetracycline 10-15 µg/mL.[151] Hydroxymethylfurfural, cinnamic acid, *β*-daucosterol, gallic acid, ellagic acid and quercetin have been isolated from the ethyl acetate fractions of 95% ethanol fruit extracts of *E. officinalis.*[152] All compounds showed antioxidant activity, except for cinnamic acid. GC-MS analysis revealed that 5- hydroxymethylfurfural (5-HMF) is the main component of *Punica granatum* Linn. (pomegranate) methanolic peel extracts, with MIC and MBC values of 125-250 µg/mL against *S. aureus.*[153] The antimicrobial properties of cinnamic acid and its derivatives have also been reported.[154] Other phenolic compounds have been identified in 60% acetone extracts of *E. officinalis*, including mucic acid 1-ethyl ester 3-*O*-gallate, mucic acid 6-methyl ester 3-*O*-gallate, and mucic acid 6-ethyl ester 2-*O*-gallate, mucic acid 1,6-dimethyl ester 2-*O*-gallate, mucic acid 1-methyl ester 2-*O*-gallate, mucic acid 1,4-lactone methyl ester 5-*O*-gallate, and mucic acid 6-methyl ester 2-*O*-gallate.[100] Further research is required to investigate the antibacterial properties of those compounds.

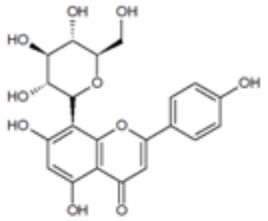
Various phenolic compounds have been identified in 85% ethanol extracts prepared from the aerial segments of *Euphorbia hirta*. including scopoletin, scoparone, isoscopoletin, quercetin, isorhamnetin, pinocembrin, kaempferol, luteolin.[155] Scopoletin have been isolated from the methanolic stem bark extract of *Aleurites moluccana* and inhibits the growth of *S. typhimurium* (MIC = 250 µg/mL).[156] Interestingly, isorhamnetin attenuates *S. aureus* induced lung cell injury by inhibiting the α-hemolysin encoding gene expression.[157] Pinocembrin has been shown to inhibit *A. hydrophila* growth (MIC = 256 µg/mL).[158] Kaempferol has weak antibacterial activity, although it synergistically potentiates the effects of colistin against colistin-resistant bacterial pathogens by reducing the MIC of colistin against *E. coli* (strain DC5262) and *K. pneumoniae* (strain FK1913) from 128 to 0.5 µg/mL and 128 to 1 µg/mL, respectively.[159]

Prenylated flavonoids such as hirtacoumaroflavonoside and hirtaflavonoside-B have been detected in whole plant methanolic *E. hirta* extracts.[160] Further research is required on these compounds to evaluate their antibacterial potential. Flavonol glycosides such as afzelin, quercitrin and myricitrin can be found in methanolic extracts of *E. hirta*, with all compounds exerting anti-plasmodium activity.[160] Thus, the antibacterial activities of these compounds should be examined further.

Kaempferol, luteolin, diosmetin (a flavone glycoside), kaempferide (a flavonol), chrysoeriol, nevadensin (flavones glycosides), pedunculin, xanthomicrol (a flavonoid), and other compounds including 3,4,5-trimethoxycinnamic acid, glycolipid, 3,4-dimethoxycinnamic acid (a phenolic), caffeic acid (a phenolic) and peinidin (an anthocyanidin) have all been identified from the crude methanolic *Ocimmum tenuiflorum* leaf extracts.[161] Only mild antibacterial activity has been observed for diosmetin against *S. aureus*, and this occurs via inhibition of the



a) R1 = H; R2 = H; R3 = OH; R4 = OH; R5 = H
b) R1 = glucose; R2 = H; R3 = OH; R4 = OH; R5 = H
c) R1 = H; R2 = glucose; R3 = OH; R4 = OH; R5 = H
d) R1 = H; R2 = glucose-(6→1)-rhamose; R3 = OH; R4 = OH; R5 = H
e) R1 = -CH2-(COH)4-C=O; R2 = OH; R3 = OH; R4 = C-CH3 (O)
f) R1 = H; R2 = glucose-(1→6)- glucose; R3 = OH; R4 = OH; R5 = H
g) R1 = H; R2 = H; R3 = H; R4 = OH; R5 = H
h) R1 = H; R2 = -O-CH3; R3 = rhamnose-(1→2)-galactose; R5 = H
i) R1 = H; R2 = H; R3 = H; R4 =H; R4 = H; R5 = H
j) R1 = H; R2 = OH; R3 = H; R4 = OH; R5 = H
k) R1 = H; R2 = glucose; R3 = H; R4 = OH; R5 = H
l) R1 = H; R2 = glucose; R3 = OH; R4 = OH; R5 = H
m) R1 = H; R2 = glucose; R3 = OH; R4 = OH; R5 = OH
n) R1 = H; R2 = H; R3 = OH; R4 = -O-CH3; R5 = H
o) R1 = H; R2 = H; R3 = H; R5 = OH; R5 = -O-CH3



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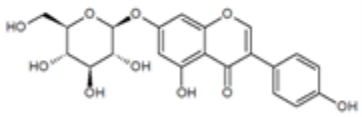

q)

Figure 1: (a) Luteolin; (b) luteolin-7-*O*-glucoside; (c) quercetin -3-glucopyranoside; (d) quercetin-3-glu-(6-1)-rha; (e) 4-methoxy quercetin -7-O-glycoside; (f) rutin; (g) apigenin; (h) 5,3,4-trihydroxy-6-methoxy-7-O-a-L-rhamnopyranosyl-(1→2)-O-b-D-galactoprranoside; (i) pinocembrin; (j) kaempferol; (k) afzelin; (l) quercitrin; (m) myritrin; (n) diosmetin; (o) chrysoeriol; (p) vitexin; (q) genistein-7-*O*-glucoside.

expression of alpha-hemolysin.[162] Synergistic effects of diosmetin in combination with erythromycin has been reported against ABC transporter-overexpressed MRSA (RN4220/pUL5054), with MIC values of erythromycin reduced from 256 to 32 µg/mL.[163] This may occur via the inhibition of MRSA pyruvate kinase by diosmetin, which then leads to a deficiency of ATP, thereby affecting the bacterial efflux pump.[163] Chrysoeriol and luteolin are also active against MRSA with MIC values of 1.25 µg/mL and 20 µg/mL, respectively.[164]

Ethanolic whole plant extracts of *Phyllanthus niruri* contain (-)-epicatechin, which has antioxidant effects in rats.[165] It is also active against *S. aureus* and MRSA-16[166] and potentiates the antibacterial activity of oxacillin by decreasing the MIC from 512 µg/mL to 1 µg/mL.[166] Compounds identified from *P. niruri* include quercetin, rutin, astragalin, quercitrin, isoquercitrin, kaempferol-4′-rhamnopyranoside, eridictyol-7-rhamnopyranoside, fisetin-4-O-glucoside, nirurin (prenylated flavanone), niruriflavone and quercitol.[71,167] Astragalin is reported to possess antioxidant, anti-inflammatory, anticancer, cardioprotective, neuroprotective, anti-obesity, antiulcer and antidiabetic activities.[168]

The whole plant of *T. purpurea* contains isolonchocarpin, pongamol, lanceolatin A, lanceolatin B, purpurenone, purpurin, semiglabrin, pseudosemiglabrin, tachrosin, apollinine, semiglabrinol, tephroglabrin, tepurindiol, serratin 7-O-[β-D-glucopyranosyl-(1-4)-β-D-glactopyranoside], terpurinflavone, karanjin, tephrosin, pongaglabol, tephropurpulin A, isoglabratephrin, glabratephrin, tephrorins A, tephrorins B, purpureamethied and rutin.[169] Noteworthy antibacterial activity of lanceolatin B has been observed against *S. dysenteriae* (MIC = 64 µg/mL),[170] whilst pongamol shows good activity against *E. coli* and *S. dysenteriae* (MIC = 128 µg/mL),[171] Field emission scanning electron microscopy (FE-SEM) experiments have revealed antibacterial properties of karanjin against *E. coli* and *S. aureus*, although MIC values were not determined in this study.[172] Antibacterial activity has also been reported for tephrosin against *E. coli, K pneumoniae* and *S. aureus* (MIC = 512 µg/mL),[173] and for pongaglabol against *S. dysenteriae* (MIC = 64 µg/mL).[174] Another study isolated four prenylflavone derivatives, (*E*)-5-hydroxytephrostachin, purleptone, (*E*)-5-hydroxyanhydrotephrostachin and terpurlepflavone, from the dichloromethane/methanol stem extracts of *T. purpurea*. Further research is required to investigate their antibacterial properties.

Aqueous fruit extracts of *Terminalia bellirica* contain furfural, 2,4-dihydro-2,4,5-trimethyl-3H-pyrazol-3-one, 2,3-dihydro-3,5-dihydroxy-6-methyl-4H-pyran-4-one, 5-(hydroxymethyl)-2-furancarboxaldehyde, 1,2,3-benzenetriol and D-allose. Further investigation is required to examine their antibacterial activities. Ferulic acid, vanillic acid, eugenol, 4-*O*-methgallic acid, rutin, quercetin, luteolin, isoquercetin, 3-methoxy quercetin,

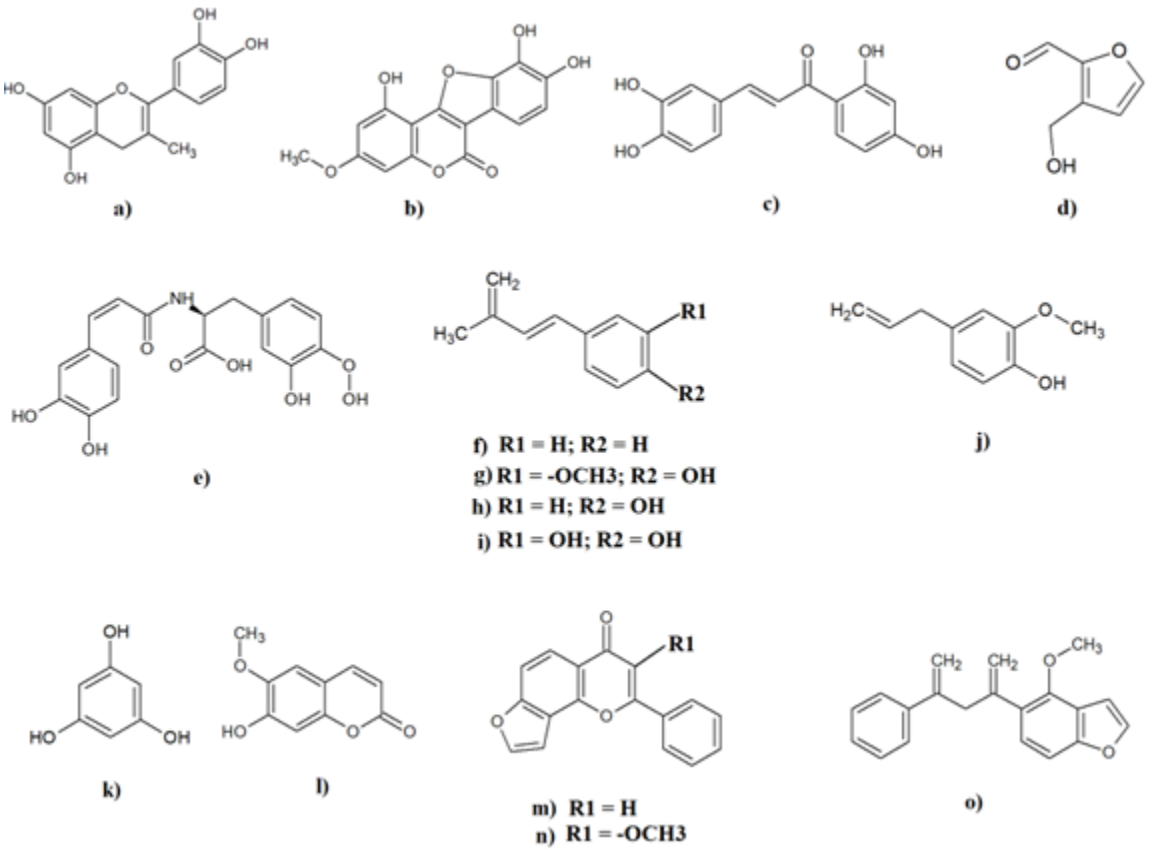

Figure 2: (a) epicatechin; (b) wedelolactone; (c) butein; (d) clovamide; (e) hydroxymethylfurfural; (f) cinnamic acid, (g) ferrulic acid; (h) p-coumaric acid; (i) caffeic acid; (j) eugenol; (k) phloroglucinol; (l) scopoletin; (m) lanceolatin; (n) karanjin; (o) pongamol.

3,4-dimethoxy quercetin *p*-coumaric acid, caffeic acid, melilotic acid, phloroglucinol and pyrogallol have been identified in the fruits of *Terminalia chebula.*[175] Ferulic acid exhibits antibacterial activity against *E. coli* and *S. aureus*, with MIC values of 100 and 1250 µg/mL, respectively.[176] Eugenol is active against *E. coli, S. dysenteriae, S. aureus* and *S. typhimurium*, with MIC values ranging from 312 to 625 µg/mL.[177] *p*-Coumaric acid has good antibacterial activity against *E. coli, S. aureus, S. dysenteriae* and *S. typhimurium*, with MIC values of 80, 20, 10 and 20 µg/mL, respectively.[178] Caffeic acid synergistically inhibits *S. aureus* when combined with norfloxacin, reducing the MIC from 156.3 µg/mL (when norfloxacin is used alone) to 15.5 µg/mL for the combination.[179] Synergy is also observed when combined with imipenem against *E. coli*, reducing the MIC of the molecule from 2500 to 1574 µg/mL.[179] Pyrogallol shows a synergistic interaction with norfloxacin and gentamicin against *S. aureus* with MIC values decreasing from 156.3 to 78 µg/mL and 49.2 to 2.4 µg/mL, respectively.[179] The phloroglucinol derivative, trialdehyde phloroglucinol**,** exhibits anti-MRSA activity (MIC = 320 µg/mL).[180] Rutin, quercetin, luteolin, isoquercetin, 3-methoxy quercetin, and 3,4-dimethoxy quercetin have been identified in the fruit of *T. chebula.*[175]

Tannins

Methyl gallate, gallic acid and catechin are three bioactive flavonoids, isolated from *Acacia nilotica* fruit pulp extracts.[181] Interestingly, the authors of that study also evaluated antibacterial properties of these compounds and reported that all inhibited bacterial growth. Some tannins including, 3-*O*-butyl-(-)-epicatechin and 3-*O*-butyl-(-)-epigallocatechin, (+)-gallocatechin, (−)-epigallocatechin, were isolated from methanolic *A. indica* dried bark.[124] Hydrolysable tannins have been identified in the fruits of *Emblica officinalis*, including corilagin, chebulanin, chebulagic acid, gallic acid, ellagic acid, elaeocarpusin, punicafolin, tercatain, mallonin, isostrcitnin, putranjivain A, and phyllanemblinin A.[182] Furthermore, phyllanemblinins B, C, D, E, and F have been reported in the leaves and branches.[182] Further studies are required to examine their antibacterial effects.

Novel dimeric dehydroellagitannins including euphorbin A and euphorbin B, have been identified in the aerial parts of 70% acetone extracts of *Euphorbia hirta.*[183] In addition, monomeric hydrolysable tannins such as 2,4,6-tri-O-galloyl-D-glucose, 1,3,4,6-tetra-O-galloyl-β-D-glucose, 1,2,3,4,6-penta-O-galloyl-β-D-glucose, and geraniin, along with terchebin and two quinic acid esters; 5-O-caffeoylquinic acid and 3,4-di-O-galloylquinic acid were also

identified. These compounds have not previously been assessed for their antibacterial properties.

The major tannins present in the fruits of *Terminalia chebula* include gallic acid, digallic acid, ellagic acid, ethyl gallate, methyl gallate, terflavin A, terchebulin, punicalagin, chebulagic acid, chebulinic acid and corilagin.[175] Gallic acid has weak antibacterial activity against *E. coli* and *S. aureus*, with MIC values of 1500 and 1750 µg/mL, respectively.[176] It also reduces the MIC of norfloxacin from 156 to 49 µg/mL, and the MIC of gentamicin from 49 to 2.5 µg/mL against *S. aureus*.[179] Other tannins reported in *T. chebula* extracts include casuarinin, chebulanin, tercatain, gemin, tellimagrandin I, punicacortein C, punicacortein D, chebulic acid, methyl chebulagate, neochebulagic acid, 6-O-methyl neochebulagate, eschweilenol C, phyllanemblinin E and phyllanemblinin F.[175] Terchebulin inhibits *Propionibacterium acnes* with MIC and MBC values of 125 µg/ml and 260 µg/ml, respectively.[184] Punicalagin possesses good antibacterial activity against *S. aureus* (MIC = 250 µg/mL),[185] whilst chebulinic acid is highly active against *M. tuberculosis*.[186] Corilagin inhibits *E. coli* and *S. aureus* growth, with MIC values of 62.5 µg/mL and 31.25 µg/mL, respectively.[187] Corilagin (MIC = 16 µg/mL) and tellimagrandin I (MIC = 50 µg/mL) potentiate the inhibitory effects of oxacillin against MRSA by reducing its MIC value from 256 µg/mL to 1 µg/mL.[188] Casuarinin has inhibitory effects in agar well diffusion assays against *S. aureus* and MRSA (ZOIs = 19-20 mm respectively).[189]

The ellagitannins corilagin and tellimagrandin I have been identified in the methanolic fruit extracts of *Terminalia bellirica*.[190] Methyl chebulanin, chebulinic acid, chebulagic acid and chebulanin are the major ellagitannins reported in that extract.[190] Other major compounds identified include 1,3,4,6-tetra-O-galloyl-β-d-Glc, 1,6-di-O-galloyl-β-d-Glc, 3,4,6-tri-O-galloyl-β-d-Glc, penta-O-galloyl-β-d-Glc, methyl and dimethyl ellagic xylosides, ellagic acid, and (S)-flavogallonic acid.[190,191] Further studies are required to explore their antibacterial potential.

Terpenoids

An essential oil prepared from *Achillea millefolium* contained thymol, carvacrol, α-pinene, limonene and borneol.[4] Nortably, thymol and carvacrol have good antibacterial activities against *E. coli* (MIC = 187.5 and 375 µg/mL) and *S. typhimurium* (MIC = 375 µg/mL).[192] The positive enantiomer of α-pinene synergistically interacts with ciprofloxacin, potentiating the inhibition of MRSA (MIC reduced from 0.5 to 0.003 µg/mL).[193] Additionally, antibacterial activity has been reported for limonene against several MRSA strains, with MIC values ranging from 2-32 µg/mL.[194] Additionally, limonene synergistically enhances the inhibition of MRSA growth when combined with gentamicin.

The limonoid mahmoodin has been identified in *Azadirachta indica* essential oil.[195] It inhibits the growth of *S. sonnei, K. pneumoniae, B. cereus* and *S. aureus* on agar (ZOIs = 15-18 mm at a concentration of 20 mg/mL).[195] Another limonoid, 17-(5-methoxy-2-oxofuran-3-yl)-28-d eoxonimbolide, and eleven other compounds including 6-deacetylnimbin, 6-deacetylnimbinal, nimbandiol nimbolide, 2′,3′-dehydrosalannol, 3*β*,4*β*,20*α*-trihydroxy-5-pregnen, 2*α*,3*β*-dihydroxy-5-pregnen-16-one, (+)-dehydro-vomifoliol, and 3*β*-hydroxy-5*α*,6*α*-epoxy-7-megastigmen-9-one, have been isolated from the methanolic leaf extract of *A. indica*.[125] All compounds show potent antibacterial activities against *E. coli* and *K. pneumoniae*, with MIC values ranging from 0.78 to 25 µg/mL.[125] Two triterpenes (β-sitosterol and lupeol) have been identified in the methanolic stem bark extracts of *Dalbergia lanceolaria*.[196] β-Sitosterol has moderate antibacterial activity against *S. aureus*, with an MIC value of 1240 µg/mL and an MBC value of 2208 µg/mL.[197] Similarly, lupeol has mild inhibitory activity against *E. coli* and MRSA.[198] In contrast, a different study reported good inhibitory activity for lupeol against a clinical MRSA BM1 strain, with MIC values of 12.5 µg/mL,[199] indicating its potency against that bacterial species.

Eighteen different meroterpene derivates (dichrostachines A-R) have been isolated from ethyl acetate dried root bark *Dichrostachys cinerea* extracts.[142] The methanolic and ethyl acetate bark extracts of *D. cinerea* contain a triterpenoid (betulinic acid) and an ester of a fatty acid (glyceryl-1-hexacosanoate).[200] Three norclerodane diterpenoids (diosbulbins K, L, and M), one enolglycoside (diosbulbinoside G), and four norclerodane diterpenoids (diosbulbins B, E, F, and G) have been identified in the *Dioscorea bulbifera* aqueous and ethanolic rhizome extracts.[201] A lupane-type triterpene, peregrinol has been isolated from dried fruit ethanol extracts of *Diospyros peregrina*.[202] More research is required to evaluate the effects on bacterial growth for all of these compounds.

Chemical fractionation of the 95% ethanolic extract of the *Eclipta prostrata* aerial segments led to the isolation of a lemmaphyllane-type triterpenoid (3β,25-dihydroxy-23E-lemmaphyll-8,23-diene), an oleanane-type triterpenoid lactone (16α-hydroxy-o lean-12-en-3-on-28,21β-olide), two oleanane-type triterpenoid saponins (3β-hydroxy-17-epi-28-norolean-12-en-16-one 3-O-β-d-glucopyranosid and 3β-O-(6-O-crotonyl-β-d-glucopyranosyl)-16α-hydroxy-olean-12-en-28-oic acid 28-O-β-d-glucopyranosyl ester) (compound-4), a beyerane-type diterpenoid (11β,17-dihydroxy-beyer-15-ene) and a guaiane-type sesquiterpenoid acid (4β-hydroxy-guai-10(14),11 (13)-dien-12-oic acid).[203] Only compound 4 showed noteworthy antibacterial activity against *S. aureus* (IC_{50} = 37.36 µM).[203] Stigmasterol and 3-acetylaleuritolic acid have also been identified within the chloroform extracts prepared from *E. prostrata* aerial segments.[145] Stigmasterol shows promising antibacterial activities against clinical strains of MRSA, with MIC and MBC values of 12.5 µg/mL for both.[199]

The compound taraxerone and a mixture of 25-hydroperoxycycloart-23-en-3β-ol and 24-hydroperoxycycloart-25-en-3β-ol (sample 2) have been isolated from dichloromethane air dried stem extracts of *Euphorbia hirta.*[204] Taraxerone and sample 2 displays antibacterial activity against *S. aureus* on agar (ZOIs = 15-16 mm) at 30 µg/well. Sample 2 produced ZOIs against *E. coli* of 12 mm.[204] Taraxerone and 1α, 12α-oxidotaraxerol have been isolated from the whole plant ethanolic extract of *E. hirta.*[205] Both compounds are active against *Shigella dysenteriae* (MIC = 128 µg/mL) and produce ZOIs on agar of 10-14 mm at 200 µg/disc against *B. cereus, E. coli, Klebsiella* sp., *S. sonnei, S. boydii, S. flexneri* and *S. typhi.*[205]

Among the many compounds identified in *Ficus religiosa*, lupeol, phytol, linalool, α-cadinol, α-eudesmol, β-eudesmol, α-amyrin are present in the leaves, whilst lanosterol, lupen-3-one in bark, lupeol are present within the roots, and β-caryophyllene, α-terpinene, α-trans bergamotene, (e)-β-ocimene, β-pinene, limonene, dendrolasine, α-ylangene, α-thujene, α-copaene, β-bourbonene, aromadendrene, δ-cadinene, α-humulene, alloaromadendrene, germacrene, γ-cadinene, and bicyclogermacrene are present in the fruits.[206] Phytol has noteworthy antimicrobial activities against *E. coli* and *S. aureus* (MIC = 125 and 62.5 µg/mL),[207] whilst linalool produced MIC values ranging from 32 to 128 µg/mL against several strains of *S. aureus.*[208]

Ursolic acid and oleanolic acid have been isolated from the methanolic leaf extract of *Ocimum tenuiflorum.*[209] Both compounds have antibacterial activity against methicillin susceptible *S. aureus* (MSSA) and MRSA, with MIC values of 8 µg/mL and 64 µg/mL respectively.[210] Methanolic leaf extracts of *O. tenuiflorum* contain farnesol, an acyclic sesquiterpene alcohol which has antibacterial effects against *S. aureus.*[211] Farnesol enhances the antibacterial effect of ampicillin by reducing its MIC from 16 to 4 µg/mL against *S. aureus* strains NRS100 (COL) and NRS123 (MW2). It also significantly lowers the MIC of oxacillin, from 256 to 8 µg/mL for the NRS100 (COL) strain and from 32 to 12 µg/mL for the NRS123 (MW2) strain.[211] It has been postulated that farnesol affects the mevalonate pathway of *S. aureus* to exert its antibacterial action.[212]

The triterpenes limonene, p-cymene, lupeol acetate, lupeol, phyllanthenol, phyllanthenone, and phyllantheol have been identified in *Pyllanthus niruri.*[167] The main chemical constituent of *Satureja horvatii* is *p*-cymene, which is active against *E. coli* and *S. typhimurium* (MIC = 30 µg/mL).[213] *Swertia chirata* contains episwertenol, gammacer-16-en-β-ol, gentianine, gentiocrucine, lupeol, oleanolic acid, ursoilic acid, chiratenol, pichierenol, swertanone, swertenol, taraxerol, and *β*-amyrin.[214] The antibacterial activity of gentianine on agar has been reported against *S. boydii* and *V. cholera* (ZOIs = 7 mm at 200 µg/100µL).[215] The main terpenoids present in *Tinospora cordifolia* include tinosporide, furanolactone diterpene, furanolactone clerodane diterpene, furanoid diterpene, tinosporaside, ecdysterone makisterone, cordifolioside A, B and C, cordifoliside D and E, tinocordioside, cordioside, palmatosides C and F, sesquiterpene glucoside tinocordifolioside, clerodane furono diterpene glucoside (amritoside A, B, C, and D) and the sesquiterpene tinocordifolin.[117] Antimicrobial activities of furan derivatives have been reported previously.[216]

Other Compounds

A C21 steroidal saponin, 2α,4α-dihydroxy-pregn-5-en-16-one-3α-*O*-D-glucopyranoside, isolated from the methanolic leaf extract of *Azadirachta indica*, has strong activity against *E. coli, E. faecalis* and *S. enterica* (MIC = 0.78 and 6.25 µg/mL, respectively).[125] Several other phytochemicals have been identified in the chloroform, ethyl acetate, methanol, petroleum ether and n-hexane leaf extracts of *Brassica juncea*. These include benzenepropanoic acid, 3,5-bis (1,1-dimethylethyl)-4-hydroxy-, methyl ester (23%, in methanol), n-eicosane (27%, in ethyl acetate), n-pentacosane (50%, in chloroform) and n-tetratetracontane (42.5 and 49%, in petroleum ether and n-hexane, respectively).[217] Antimicrobial studies have not been performed with these compounds, and substantially more work is required.

Two novel aromatic compounds (simalin A and simalin B) and five previously identified compounds, shamiminol, (−)-epicatechin-7-O-β-xylopyranoside, (−)-catechin-7-O-β-xylopyranoside, (+)-isolarisiresinol-9′-O-β-glucopyranoside and (+)-lyoniresinol-9′-O-β-glucopyranoside were identified in 70% methanolic stem bark extracts of *Bombax ceiba*.[218] The xanthones, isomangiferin, mangiferin, and 7-O-methyl mangiferin, as well as the four coumarins esculetin, scopoletin, fraxetin and scopoline have been identified in the 70% methanolic flower extract of *B. ceiba*.[130] Mangiferin (4 mg/disc) synergistically inhibits *S. aureus* growth on agar in combination with nalidixic acid, ampicillin, tetracyline, and sulfamethoxazole/trimethoprim.[219]

Fistulains A and B (bischromones) have been identified in the bark extracts of *Cassia fistula.*[220] GC-MS analysis has revealed the presence of octahydro-cis-1H-indene, 1-butyl-cyclohexene and butyl-cyclohexane in the n-butanol soluble parts of *C. fistula* methanolic flower extracts.[221] Other phytochemicals identified idenbtified in that study include 9-heptadecanol, tetradecamethyl-cycloheptasiloxane, hexadecamethyl-cyclooctasiloxane, octadecamethyl-cyclononasiloxan, *n*-hexadecanoic acid.[221] The literature has documented n-hexadecanoic acid, butyl-cyclohexane and behenic alcohol as having antimicrobial properties.[221] GC-MS analysis identified 2-methyl-butanoic acid, penthiophane (2H-thiopyran, tetrahydro) and isopropyl acetate in the chloroform fraction of *C. fistula* fruit pulp.[222] These compounds have antifungal activity,[222] and should be investigated further to explore their antibacterial properties.

Cannabidiolic acid (CBDA) and cannabidiol (CBD) have been identified in ethanolic extracts of the fiber-type strain of *Cannabis sativa.*[20] Both compounds show strong inhibitory effects on *S. aureus* and MRSA, with MIC values of 2-4 μg/mL and 1 μg/mL, respectively. Combinations of CBD with the reference antibiotics clindamycin, tobramycin, vancomycin, methicillin, ofloxacin, meropenem, and teicoplanin were undertaken against MRSA, but the interactions were indifferent.[20] The ethanolic flower extract of *C. sativa* appears to have potent activity against *B. cereus* on agar (ZOI = 37 mm) and in microdilution broth assays (MIC = 5 μg/mL).[223] Furthermore, isolated bioactive compounds such as Δ9-tetrahydrocannabinol (THC), and CBD show antibacterial activity against *B. cereus* (ZOIs = 8.5-12 mm and MIC = 60 μg/mL). *Celosia argentea* seeds and leaves contains around 79 compounds including saponins, peptides, phenols, fatty acids, and amino acids. Its active ingredients are triterpenoid saponins which include celosin A, celosin B, celosin C, celosin D, and other celosins. More research is needed to investigate their antibacterial capabilities.

Essential oils prepared from *Cinnamomum tamala* leaves contain trans-cinnamaldehyde and 5-(2-propenyl)-1,3-benzodioxole. Additionally, thirty-nine compounds have been identified and isolated from the methanolic bark extract of *Cinnamomum zeylanicum* using GC-MS.[224] Extracts of those species inhibit the growth of *E. coli, K. pneumoniae, P. mirabilis* and *S. aureus* on agar (ZOIs = 5-6 mm), although these low ZOIs indicate only weak antibacterial activity. It has been postulated that (*E*)-cinnamaldehyde is responsible for the antibacterial activities of *C. zeylanicum* crude methanolic bark extracts.[224] Furthermore, commercial cinnamaldehyde, when used at 800 μM, inhibits the growth of *E. coli* O157:H7, suggesting that this compound contributes to the antimicrobial activity of *C. zeylanicum* extracts.[225] The plant sterol *β*-sitosterol-D-glucopyranoside, which was isolated from a 70% methanolic leaf extract of *Desmostachya bipinnata*, inhibits the growth of *E. coli, K. pneumoniae, V. cholera, S. aureus* and *S. dysenteriae*, producing MIC values ranging from 6 to 50 μg/mL.[226] Furthermore, whenpaired with ciprofloxacin, gentamicin, andchloramphenicol, β-sitosterol-D-glucopyranoside potentiated the inhibition of bacterial growth.

Desmodium species contain coumarone-chromones, pterocarpans, triterpenoids, saponins, tetrahydro-isoquinolones, phenylethylamines, indole-3-alkylamines, and multiple lipids.[114] Phenolic glycosides such as gangeticoside, leonuriside A, as well as the compounds methyl benzoate 2-O-*β*-D-glucopyranoside and tortoside-A have been identified in the methanolic extract of the aerial segments of *Desmodium gangeticum.*[227] Aminoglucosyl glycerolipid and glycosphingolipid (cerebroside) have been identified in the *D. gangeticum* ethanolic whole plant extracts, and both compounds have anti-parasite activity against *Leishmania donovani.*[228] However, studies examining the antibacterial activity of these compounds are lacking and further research is required to investigate their antibacterial potential.

The bafoudiosbulbins A, B, C, F, G, and 2,7-dihydroxy-4-methoxyphenanthrene, which were isolated from methanolic *Dioscorea bulbifera* bulbil extracts, inhibit *E. coli* and *K. pneumoniae* growth (MIC = 64-256 μg/mL).[34] Bafoudiosbulbin A and B inhibit the growth of *S. typhi, S. paratyphi* A and *S. paratyphi* B (MIC values ranging from 25-50 μg/mL).[229] Six steroidal saponins diosgenin, β-sitosterol, stigmasterol, daucosterol, diosgenin-3-O-alpha-L-rhamnopyranosyl (1→2)-β-D-glucopyranoside (prosapogenin A of dioscin, 5) and diosgenin-3-O-[di-alpha-L-rhamnopyranosyl (1→2,1→3)]-β-D-glucopyranoside (taccaoside, 6) have been isolated from the tubers of *D. bulbifera.*[230] Diosgenin has modest antibacterial activity against *E. coli* and *S. aureus*, and when combined with norfloxacin, it reduces the MIC against *E. coli* from 322 to 128 μg/mL. Similarly, when combined with gentamicin diosgenin reduces the MIC against *S. aureus* from 25 to 8 μg/mL. Eleven steroidal saponins (dioscoreanosides A-K) were isolated from an 85% methanolic *D. bulbifera* flower extract and have been identified, although their antibacterial properties have not been investigated. Eclalbasaponin was been isolated from methanolic leaf extracts of *Eclipta alba* inhibits *B. subtilis* and *P. aeruginosa* growth (MIC = 94-188 μg/mL).[231]

Ethyl brevifolin carboxylate, methyl brevifolin carboxylate (coumarins), 4-methoxy-nor-securinine, nirurine, β-sitosterol, ricinoleic acid, diosgenin, niruriside, triacontanal and tricontanol have been identified in *Phyllanthus niruri.*[167] Various lignans have also been identified *P. niruri* whole plant extracts, including phyllanthin hypophyllanthin, niranthin, nirtetralin, phyltetralin, hinokinin, lintetralin, isolintetralin, 2,3-desmethoxy seco-isolintetralin, linnanthin, nirphyllin, phyllnirurin and demethylenedioxyniranthin.[167] Whilst phyllanthin is itself inactive against *S. aureus, E. coli* and *S. typhimurium*, it has been reported to potentiate the effects of norfloxacin against *S. aureus* A1199-B, which overexpresses the NorA efflux pump.[232] These findings suggest that phyllanthin may inhibit that efflux pump, although this remains to be tested. Further research is required to investigate the antibacterial activities of this and other compounds from *P. niruri. Tephrosia purpurea* has been reported to contain hexadecenoic acid, linoleic acid, cieritol, purpdione, tetradecanoic acid, maackiain, tephrosone, (+)-tephropurpurin, purpuritenin, and β-sitosterol,[169] and some of those compounds may contribute to the antibacterial activity of that species, although this remains to be verified.

The various compounds that have been identified in *Tinospora cordifolia* include giloinsterol, β-sitosterol, 20a- hydroxy ecdysone, syringin, giloin, tinosporan acetate, tinosporal acetate, tinosporidine, heptacosanol, octacosanol, sinapic acid, and tinosponone.[117] Sinapic acid has moderate antibacterial activities against *E. coli* and *S. aureus*, with MIC values of 700 and 300 μg/

mL, respectively.[233] The methanolic extract of the *Malva sylvestris* aerial segments contain 1-heptacosanol as the major compound which has mild activity against *E. coli, K. pneumoniae* and *S. aureus* (MIC = 2190-5190 µg/mL).[234]

The 50% ethanolic whole plant extracts of *Swertia chirayta* contain numerous phytochemicals that include swertiachiralatone A, swertiachoside A, swertiachirdiol A and swertiachoside B, isoorientin, mangiferin, djalonenol, 2-C-β-d-glucopy-ranosyl-1,3,7-trihydroxyxanthane, 8-O-[β-d-xylopyranosyl-(1 → 6)-β-d-glucopyranosyl]-1,7-dihydroxyl -3-methoxyxanthone, 8-O-[β-d-xylopyranosyl-(1 → 6)-β-d-glucopyranosyl]-1-hydroxyl-3, 7-dimethoxy-xanthone, 1-O-β-d-glucopyranosyl-3,5,8-trihydroxyxanthone, 7-O-[β-d-xylopyranosyl-(1 → 2)-β-d-xylopyranosyl]-1,8-dihydroxy-3-methoxyxanthone, 1,5,8-trihydroxyl-3-me thoxyxanthone, 1-hydroxy-3,7-dimethoxyxanthone, epi-syringaresinol-4″-O-β-d-glucopyranoside, syringaresinol 4″-O-β-d-glucopyranoside, 6′-O-β-d-glucop yranosylgentiopicroside, 6′-O-β-d-glucopyranosylsweroside, swerbimalactone B, 3β-hydroxy-11-oxo-olean-12-enyl-3-palmitate, erythrodiol-3-O-palmitate, olean-12-ene-28-carboxy-3β-hexadecanoate, cholest-4-en-3-one, 3,3′,5-trihydroxybiphenyl and bridelionoside B.[235] Other compounds identified in *S. chirayita* are amarogentin, swertiamarin, amaroswerin, gentiopicrin, sweroside, swerchirin, isobellidifolin, secoisolariciresinol, chiratnin, decussatin, kairatenol, magnostin, syringaresinol, and *β*-sitosterol-3-*β*-D-glucoside.[214,236] Interestingly, swertiamarin outperforms ciprofloxacin in its antibacterial activities against *K. pneumoniae*, MRSA, and *E. coli*, inhibiting growth by 50-80% at doses of 2.5 µg/mL.[237] Furthermore, when swertiamarin is combined with quercetin, strong antibacterial activity is observed against *E. coli, P. mirabilis*, and MRSA, which is comparable to ciprofloxacin. Swerchirin and isobellidifolin have antifungal activity and should be studied further for their antibacterial properties.[237] Polyphenols have been identified in the cyclohexane dried immature fruits extracts of *Solanum nigrum* and these include gallic acid, catechin, protocatechuic acid, caffeic acid, epicatechin, rutin, naringenin, *p*-hydroxycinnamic acid, acanthoside D, 3-caffeoylquinic acid methyl ester, cinnacassoside A.[119]

CONCLUSION

Herbal remedies, rooted in ancient traditional systems such as Ayurveda, Traditional Chinese Medicine, Kampo, Siddha, and Unani, take a holistic approach to preventing disease and promoting health through medicinal plants. Ayurveda, in particular, is known as the "science of life," with its core objective being the promotion of well-being and disease prevention. According to the World Health Organization (WHO), approximately 80% of the global population relies on herbal therapies for their healthcare needs (often in combination with allopathic medicine). Given the accelerating spread of antimicrobial resistance (AMR) and the emergence of multidrug-resistant pathogens, especially in gastrointestinal (GI) infections, traditional herbal systems offer a promising alternative. Diarrhoea remains a leading cause of mortality and malnutrition in children under five, and resistant strains such as fluoroquinolone-resistant *E. coli* and MRSA complicate treatment efforts. Ayurvedic botanicals, known for their rich content of bioactive secondary metabolites, represent a valuable source for novel antibacterial agents.

This review has emphasised the importance of traditional Ayurvedic plants in managing diarrhoeal diseases, highlighting phytochemicals such as flavonoids, phenolic acids, tannins, and terpenoids that demonstrate antibacterial potential. However, a significant gap in the literature must be acknowledged, most studies to date have focused either on antibacterial activity alone, or on phytochemical profiling in isolation, with very few integrating both within a single study. This limits our understanding of the direct relationship between bioactive compounds and observed antimicrobial effects. Moreover, the majority of studies employ a narrow bacterial panel, often limited to a few standard laboratory strains that may not reflect the resistant clinical isolates currently posing major health threats. Additionally, relatively few studies have examined the effects of the traditional therapies (and/or their isolated compounds) against antibiotic-resistant bacterial strains. There is a clear need to expand the spectrum of pathogens tested, particularly focusing on drug-resistant clinical strains relevant to GI infections.

Another critical shortcoming is the widespread focus on single-plant extracts, whereas Ayurvedic formulations commonly consist of polyherbal combinations. Evaluating such combinations for synergistic or antagonistic effects could provide insights into their real-world effectiveness and pharmacodynamics. In addition, toxicological assessments are rarely reported alongside antibacterial findings, making it difficult to assess the safety profile of promising extracts or compounds.

Future studies should integrate both phytochemical analysis and antibacterial testing in a unified approach to identify bioactive molecules and link them directly to antimicrobial activity. Antibacterial assays should include clinically relevant resistant strains, not just standard reference strains. Research should explore polyherbal combinations, reflecting traditional Ayurvedic formulations, to assess synergistic or additive effects. Studies must incorporate toxicity evaluations—including cytotoxicity assays or animal safety models—to ensure therapeutic relevance and safety. Standardised methodologies should be encouraged for extract preparation to allow better cross-comparison and meta-analysis. By addressing these limitations, future research can more effectively validate and harness the therapeutic potential of Ayurvedic botanicals in combating antibiotic-resistant GI pathogens.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

ABBREVIATIONS

GI: Gastrointestinal; **AMR:** Antimicrobial resistance; **WHO:** World Health Organization; **ZOI:** Zone of inhibition; **MIC:** Minimum inhibitory concentration; **MBC:** Minimum bactericidal concentration; **MSSA:** Methicillin susceptible *Staphylococcus aureus*; **MRSA:** Methicillin resistant *Staphylococcus aureus*; **VRSA:** Vancomycin resistant *Staphylococcus aureus*; **THC:** Tetrahydrocannabinol; **CBD:** Cannabidiol; **LC-MS:** Liquid Chromatography-Mass Spectrometry; **EO:** Essential oil; **DMSO:** Dimethyl sulfoxide; **ROS:** Reactive oxygen species; **GSH:** Glutathione; **GSSG:** Glutathione disulphide; **DPPH:** 1,1-Diphenyl-2-picrylhydrazyl; **TFC:** Total flavonoid content; **TPC:** Total phenolic content.

SUMMARY

Ayurvedic medicinal plant extracts exhibit diverse levels of *in vitro* antibacterial activity against both Gram-positive and Gram-negative pathogens.

These plants are known to be rich sources of bioactive constituents, including flavonoids, tannins, alkaloids, terpenoids, and phenolic acids, which may be responsible for their observed antimicrobial and antioxidant properties.

Numerous plant extracts have demonstrated significant antioxidant potential, primarily through mechanisms involving free radical scavenging and the reduction of oxidative stress, which may enhance their antimicrobial efficacy.

While existing studies support the in vitro effectiveness of these extracts, further investigations are required to standardise extraction methods, assess toxicity profiles, and validate their clinical applicability.

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