

A Review of Ayurvedic Principles and the use of Ayurvedic Plants to Control Diarrhoea and Gastrointestinal Infections

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ABSTRACT

According to the World Health Organisation (WHO), diarrhoea is the second leading cause of death in children under the age of five. It is a common symptom associated with gastrointestinal bacterial infections. Many antibiotics have lost their efficacy due to the rapid emergence of Antimicrobial Resistant (AMR) bacterial pathogens. Traditional Ayurvedic medicinal plants are likely to play a significant role in the development of new effective and safe therapies in the fight against AMR in gastrointestinal bacteria. Recent research has reported the effectiveness of numerous different Ayurvedic medicines in the treatment of gastrointestinal infections. One example is Triphala, which is a polyherbal formulation consisting of an equal mixture of dried fruit powders from the three Ayurvedic plants *Terminalia bellirica* (Gaertn.) Roxb., *Terminalia chebula* Retz. and *Embllica officinalis* Linn. This review discusses the principles of Ayurveda and summarises the traditional use of Ayurvedic plants in the treatment of diarrhoea, dysentery, and stomach discomfort.

Keywords: Ayurvedic plants, Traditional medicine, Anti-microbial resistance, Gastrointestinal, Diarrhoea, Polyherbal formulation, Toxicity, Phytochemicals.

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Received: 17-09-2023;

Revised: 05-10-2023;

Accepted: 20-10-2023.

INTRODUCTION

As stated by the World health organisation (WHO), approximately 80% of the global population either use traditional medicines as their primary healthcare mode, or incorporate herbal remedies with allopathic medicines to promote well-being.¹ Indeed, the annual market for herbal medicines has reached \$US60 billion and WHO has highlighted the potential of traditional medicines for future drug discovery.² Ayurveda is one of the oldest healing sciences that remains in widespread usage, having originated more than 5000 years ago.³ In India, Ayurveda is referred to as the science of life, with its main objective to promote optimal health and to prevent disease.⁴ In contrast to modern allopathic medicine, Ayurveda is not restricted to alleviating disease symptoms whilst allowing the body to heal itself, but adopts a holistic approach to healthcare that places an emphasis on disease prevention.⁴

Gastrointestinal (GI) infections pose a significant risk to public health and are an economic burden on the health system due to

the rapid emergence of antibiotic-resistant pathogens.⁵ Diarrhoea is the most common manifestation of GI infections, with almost 1.7 billion cases of childhood diarrhoea reported annually worldwide.^{5,6} Indeed, diarrhoea is the second leading cause of death and malnutrition in children under five years old.⁶ Thus, safe and effective new therapies are desperately required. Diarrhoeal infections are caused by bacterial, viral and parasitic pathogens that are often acquired and transmitted by contaminated food or water.

Many anti-microbial drugs have lost their potency due to the rapid emergence of resistant pathogens. Fluoroquinolone resistance has increased across the Enterobacteriaceae, and an increase in the prevalence of Methicillin-Resistant *Staphylococcus aureus* (MRSA) infections are also a significant burden on global health care systems.⁷ Such resistances lead to treatment failure in urinary and GI tract infections, skin infections, sexually transmitted diseases, and enteric fever. Examples of the mechanisms of antimicrobial resistance (AMR) are shown in Figure 1. These include enzymatic inactivation of the antibiotic, drug target site modification, prevention of drug uptake, decreased intracellular antibiotic levels via efflux pumps, biofilm formation and plasmid-borne resistant genes.⁸ The global increase in AMR has led to an urgent need for novel, safe and effective therapies to address the high levels of microbial resistance.



DOI: 10.5530/pc.2023.4.25

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Traditional herbal medicines are likely to play an indispensable role in the development of new therapies to fight against AMR GI pathogens. Herbal medicines contain many secondary metabolites (alkaloids, flavonoids, phenolic acids, tannins, terpenoids etc.), which play critical roles in their adaptability within the harsh environments in which they grow.⁸ Ayurvedic medicines are attractive options for the development of new anti-biotic chemotherapies as their component plants are generally easy to access and are cost effective, while their efficacy is often supported by a growing volume of evidence-based research.⁹

There are many examples of recent studies reporting the effectiveness of several Ayurvedic medicines to treat GI ailments. These include *Triphala churna*, which comprises an equal mixture of dried fruit powders of the three Ayurvedic plants *Terminalia bellirica* (Gaertn.) Roxb. *Terminalia chebula* Retz. and *Embllica officinalis* Linn.¹⁰ Noteworthy antibacterial activities of aqueous and methanolic Triphala extracts have been reported against multiple bacteria, including *Escherichia coli*, *Enterococcus faecalis*, *Aeromonas hydrophila*, *Salmonella typhimurium*, *Staphylococcus aureus*, *Bacillus cereus*, *Shigella sonnei* and *Shigella flexneri*, with minimum inhibitory concentrations (MICs) in the range of 250-750 µg/mL.¹⁰ The essential oils prepared from the aerial segments of the Ayurvedic plant *Achillea millefolium* Linn. possess strong antibacterial action against *B. cereus*, *C. freundii*, *E. faecalis*, *E. coli*, *S. typhimurium* and *S. aureus*, with MIC and minimum bactericidal concentration (MBC) values ranging from 2.5-5 µg/mL and 5-10 µg/mL, respectively against the various bacterial pathogens.¹¹ Similarly,

Aconitum heterophyllum Wall. Ex Royle root extracts have good antibacterial activity against *S. aureus*, producing an MIC of 125 µg/mL.¹² This review discusses 40 different Indian plants commonly used in Ayurvedic medicine for the treatment of diarrhoea and their antibacterial properties. Additionally, the phytochemical constituents of some noteworthy species have also been reviewed.

MATERIALS AND METHODS

Scientific and traditional medicine literature was searched using several online databases including Scopus, Science Direct, Springer Link, Wiley, PubMed, Google Scholar, and Elsevier. Additionally, other articles were identified via citations in other identified publications, or via websites. Examples of key phrases used in the search are “Ayurvedic plants in diarrhoea” and “antibacterial Ayurvedic plants”. All plant species names were confirmed by using <http://www.worldfloraonline.org/>. Traditional and scientific names were used to identify essential information.

RESULTS

Principles of Ayurveda

There are six primary manuscripts that record and explain the basis of the Ayurvedic medical system: Charak Samhita, Susrut Samhita, Ashtang Hridaya Samhita, Madhav Nidan Samhita, Sarangdhar Samhita and Bhavprakash Samhita.^{4,13,14} Ayurveda adopts the principle that the universe and the human

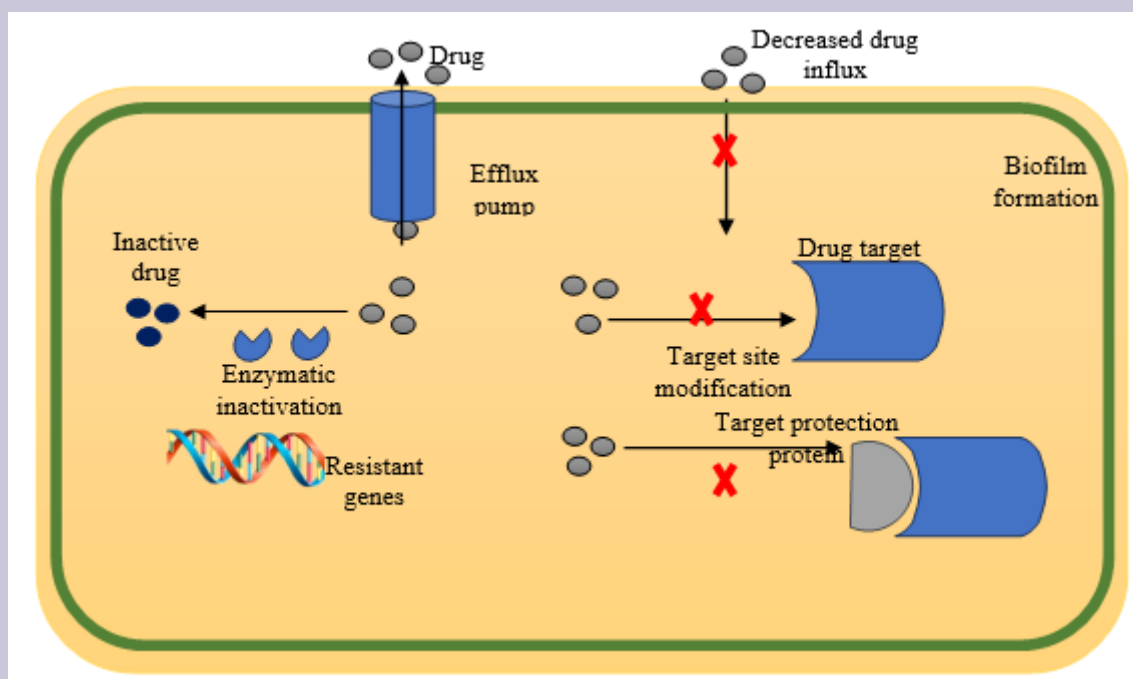


Figure 1: Anti-microbial bacterial resistance mechanisms.

body are made up of five elements (fire, earth, ether, water, and air) and an imbalance of these elements in the body leads to doshas, which subsequently cause different diseases.^{3,4,9} Doshas are classified as vata, pitta or kapha (Figure 2).^{3,4,9,13,14} Vata is related to ether and air, and regulates respiration, circulation, nerve impulse and elimination of toxins. Pitta is related to water and fire, and functions to regulate metabolism at the cellular level. Kapha is composed of water and earth and is responsible for growth and protection.

Two approaches are used in Ayurveda for the effective treatment or prevention of doshas. These include the use of a single plant herb or incorporating polyherbal formulation (PHF) that target specific health aspects.¹⁵ PHFs are typically used to achieve extra therapeutic effects (or synergistic outcomes) compared with mono-floral therapies at low doses due to the presence of different compatible phytochemicals within the formulation. Also, improvements in patient compliance can be achieved with PHF by eliminating the need to self-administer more than one herbal formulation concurrently.¹⁵ PHF is a holistic treatment approach that attempts to balance the doshas in the body via synergism. Alternatively, the different plant components in the formulation may function via different mechanisms or bind to different biological targets to elicit their effects.

Ayurvedic synergism may be governed by pharmacokinetic and pharmacodynamic mechanisms.¹⁶ Pharmacokinetic synergism operates by the concept of “Yogvahi” (Yog=drug complex; Vahi=transporter) and involve one or more herbs that increase the absorption, distribution, metabolism, and elimination of the other herbs to enhance therapeutic outcomes while minimising adverse drug reactions.¹⁷ For example, the anti-asthmatic effects of *Adhatoda vasica* Nees leaves is enhanced by the addition of *Piper longum* L.¹⁷ Interestingly, piperine, an alkaloid isolated from *P. longum*, is used in fixed-dose combinations with the drugs rifampicin and isoniazid and is marketed as Risorine™ to treat tuberculosis in allopathic medicine. The inclusion of piperine allows for a reduction in the dose of rifampicin from 450 to 200 mg by yielding up to 60% improvement in rifampicin bioavailability.¹⁷ This is an example of the potential for the development of effective new therapies utilising Ayurvedic plants. Notably, this combination not only increases the efficacy of the therapy but may also reduce the development of further antibiotic-resistant bacteria because it allows for reduced dose of rifampicin to be used. Epidemiological studies have explained the direct relationship between high doses and/or overuse of antibiotics with the emergence of resistant bacterial strains.¹⁸

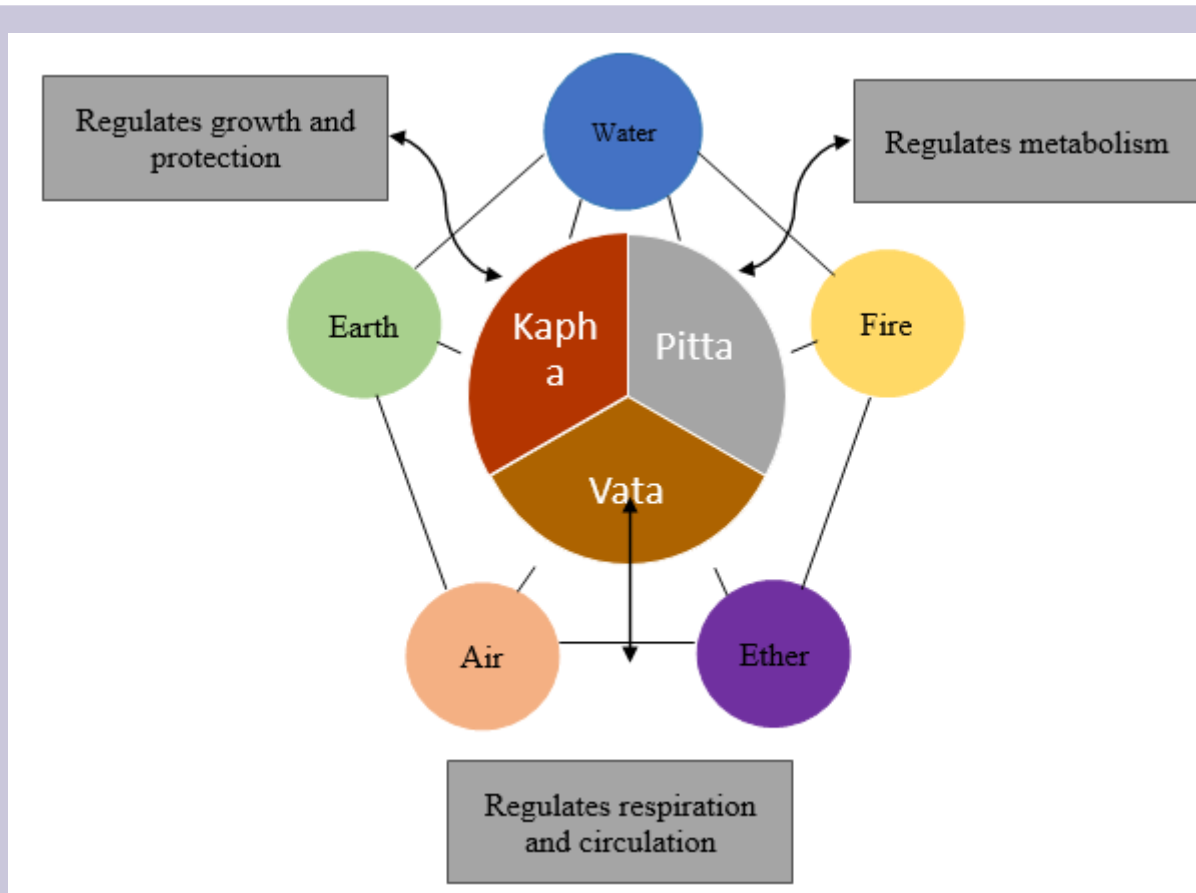


Figure 2: Ayurvedic doshas and respective elements.

Pharmacodynamic synergistic interactions arise when active phytochemicals with similar therapeutic activities target similar or multiple receptor sites simultaneously. For example, the essential oil of *Cymbopogon citratus* (DC.) Stapf (lemongrass) contains geranial, neral, and myrcene in abundance.¹⁷ The *in vitro* antibacterial activity of geranial and neral is increased by the presence of myrcene via molecular synergy. Similarly, ‘Trikatu’ consists of *Zingiber officinale* Rosc. (ginger), *Piper longum* L. (long pepper) and *Piper nigrum* L. (black pepper) in equal ratios. Trikatu is prescribed for coughs, colds, asthma, digestive problems, and to improve the pharmacokinetic properties of certain conventional antibiotics including ampicillin and levofloxacin.^{17,19-21}

Ayurvedic texts such as Charaka Samhita and Sushruta Samhita discuss special yogvahi, such as Anupana and Sehpaan.^{14,17} Anupana means “carrier properties of food” (hot water, milk, honey etc.) or any substance that is used with medicine to enhance its therapeutic effects. For example, Ghrita (also called ghee or clarified butter) is used during the manufacturing process of some Ayurvedic medicines to increase their potencies. Trikatu, sesame oil and calcinated gold are general yogvahi that are commonly used in Ayurvedic preparations.

Unfortunately, PHFs are frequently used incorrectly, as has been documented in Charaka Samhita.¹⁵ This document discusses the starting material, habitat, and growing season, harvesting conditions, method of storage and pharmaceutical processing of the plants used. Thus, the standardisation of PHF preparations has proven difficult. However, the Ayurvedic pharmacopoeia of India provides monographs on the preparation of standardised single and compound drugs formulations, and this is regulated under the Drugs and Cosmetics Act (1940).¹⁵ However, these guidelines are not strictly adhered to by some Ayurvedic therapists, nor are they regulated by the Indian government. Therefore, chemical profiling and toxicity studies on Ayurvedic medicines are crucial to ensure safety and efficacy.

The combination of allopathic drugs with Ayurvedic medicines can also lead to undesirable adverse effects due to drug-herb interactions. Warfarin co-treatment with fenugreek can increase bleeding events, whilst the therapeutic effects of lithium decrease when co-administered with the herbal diuretics *Tribulus terrestris* Linn. or *Syzygium cumini* Linn.²² The Ayurveda medicinal system has classified interactions into several categories including herb-herb, herb-food, herbs with drugs with animal origin, and herbs combined with drugs from mineral origin.²² Furthermore, it is advised that of Ayurvedic medicines should only be used under the supervision of a registered Ayurvedic practitioner, pharmacist, or qualified physician to avoid adverse drug reactions.

Traditionally, five techniques are used to prepare Ayurvedic medicinal herbs. These are Svarasa (fresh juice), Kvatha

(decoction), Kalka (crushed pulp or paste), Hima (cold infusion) and Yhant (hot infusion).⁹ Additional techniques include Siddha taila (medicated oil), Churtta (powder) and Ghrita (medicated ghee). Powdered forms of plants are commonly prepared using a mortar and pestle, although grinders are now also frequently used to reduce powder preparation time. Powders are generally taken with water or milk in a ratio of 1:4. Fermented Ayurvedic medicines include arishtas (fermented decoctions) and asavas (fermented infusions), which may be employed to increase their potency and absorption and to render them less toxic.²³ Asava-arishtha is a continuous hydro-alcoholic extraction method in which herbal medicines are prepared by allowing herbal juices (or their decoctions and sugars) to undergo fermentation. The benefits of fermentation include increased medicinal bioavailability due to the presence of a wider profile of active ingredients and the reduced toxicity of some harmful plant ingredients.²³ The Ayurvedic medicines abhayarishtha, amitarishtha, punarnavadyarishtha and rohitakarishtha utilise the active plant herbs *Terminalia chebula*, *Tinospora cordifolia*, *Zingiber officinale* and *Tecomella undulata* (Roxb.) and are all prepared using asava-arishtha extraction methods.²³ Contrastingly, bhasmas, which are unique Ayurvedic metallic medicines prepared with herbal juices, are traditionally used to treat various chronic ailments such as tuberculosis, asthma, diabetes, stomach, and blood disorders.²⁴

Rasayana medicines are used in Ayurveda to treat GI disorders due to their ability to increase immunity and because of their relative high antioxidant capacity, adaptogenic effects, and free radical scavenging properties.²⁵ Furthermore, Rasayana Ayurvedic medicines have components with additional therapeutic properties including vayasthapana (slowing the aging process), aayuskara (increasing lifespan), medha balakara (enhancement of cognitive function), balakara (promoting anabolic effects) and roga-apaharana (enhancement of immunity).²⁵ Rasayana medicines are specialised formulations, which can be prepared with single or multiple plant components and subsequently used for defined periods alongside a strict diet and lifestyle constraints. Various plant parts including leaves, fruits, flowers, stems, barks, roots, and the whole plant may be used to prepare Rasayana medicines.

Free radicals play key roles in numerous disease states as they can damage cellular membranes, cell mitochondria and DNA. For example, rotavirus and *Salmonella* spp. infections stimulate the production of Reactive Oxygen Species (ROS), which subsequently induce an imbalance of the reduced glutathione (GSH)/oxidised glutathione (GSSG) ratio.²⁶ The production of ROS is a host immune response during GI infections which depletes GSH (the main antioxidant molecule within intestinal epithelial cells) as it donates electrons to stabilise the ROS. Rasayana medicines are predominantly used by traditional healers

Table 1: Traditional use of selected Indian Ayurvedic plant herbs in the management of diarrhoea.

Plant Species	Common Name	Family	Plant part used, Indications, Reference
<i>Achillea millefolium</i> Linn.	Yarrow, Gandna, Biranjasif	Asteraceae	Leaves and the flowering tops are eaten to treat fever and numerous gastric problems. ²⁷ Leaf infusion is taken three times daily in the form of tea without milk and sugar to treat stomach discomfort. ²⁸
<i>Aconitum heterophyllum</i> wall. Ex Royle	Atis, Atees, Ativisha, Patish	Ranunculaceae	A root decoction is taken orally as one or two teaspoons daily for stomachache. ²⁸ Root juice is taken orally to cure diarrhoea, fever, and abdominal pains. ²⁷
<i>Achyranthes aspera</i> Linn.	Latjira, Chirchita, Puthkanda	Amaranthaceae	The whole plant juice is used to treat abdominal pain and dysentery. ²⁹ Leaf juice is prepared with buttermilk and taken orally to treat dysentery. ³⁰
<i>Azadirachta indica</i> A. Juss.	Neem	Meliaceae	Two teaspoons of the leaf decoction are taken orally once daily to treat digestive and gastric problems. ²⁹ Infusions made from leaves are useful to treat unspecified intestinal complaints. ³¹ Boiled leaf extracts are taken orally to treat diarrhoea. ³²
<i>Bauhinia variegata</i> Linn.	Kachnar, Gurial	Cesalpiniaceae	Boiled flowers are eaten to relieve dysentery and hemorrhoids. ³² Dried flower powder is given orally daily with water to treat dysentery in infants. ³³
<i>Boerhavia diffusa</i> Linn.	Ghass, Punarnava	Nyctaginaceae	Root powder is taken orally with water in the treatment of diarrhoea and dysentery. ³³
<i>Berberis lycium</i> Royle.	Daruhaldi, Berberry	Berberidaceae	Fresh fruit extract is taken orally to treat diarrhoea, stomach pain and intestinal problems. ²⁸
<i>Brassica juncea</i> (Linn.) Czern.	Vadisha, Indian mustard	Brassicaceae	A decoction prepared from the whole plant is taken orally to treat dysentery. ³⁴
<i>Butea monosperma</i> (Lam.) Kuntze	Dhak, Tesu, Paras, Palash	Fabaceae	Stem bark juice is taken orally to treat dysentery. Flowers are used to treat diarrhoea. ^{33,35,36}
<i>Bombax ceiba</i> Linn.	Sembar, Semal	Bombacaceae	Gum is taken orally to treat diarrhoea. ³⁷ Calyx powder is taken orally to treat stomach ache and dysentery. ³³ Root bark paste is prepared with 30-50 mL water and administered in the morning on an empty stomach for two days for the treatment of diarrhoea. ³⁸
<i>Cassia fistula</i> Linn.	Amaltas, sonalu	Fabaceae	Fruit pulp is taken orally to treat diarrhoea and dysentery. ³³ Dried seed powder is mixed in 200-250 mL water or a cup of tea and given twice a day for 3 days to treat diarrhoea. ³⁹
<i>Cannabis sativa</i> Linn.	Bhang, Ganja	Cannbinaceae	Powdered plant is mixed with coconut water and taken orally for a week to cure diarrhoea. ³⁷ Leaves are grounded with water and filtered, and two teaspoons taken orally twice daily to treat dysentery. ³²
<i>Celosia argentea</i> Linn.	Salera	Amaranthaceae	Seed powder is taken orally with water to treat diarrhoea. Leaf juice is taken orally twice a day for two days to treat dysentery. ³³
<i>Cissampelos pareira</i> Linn.	Patha, Patindu	Menispermaceae	Crushed leaves are taken orally with milk or honey to treat dysentery and gastric complaints. ²⁷ Leaf powder is consumed with water to treat dysentery. ³³

Plant Species	Common Name	Family	Plant part used, Indications, Reference
<i>Cinnamomum tamala</i> T.Nees and Eberm.	Tejpat, Bay leaves	Lauraceae	Leaf extract is taken orally to treat diarrhoea. ³²
<i>Cinnamomum verum</i> J.Presl	Dalchini, Cinnamon	Lauraceae	Bark extract is taken orally for the treatment of diarrhoea and indigestion. ⁴⁰
<i>Coriandrum sativum</i> Linn.	Dhanyaka, Dhania, Chinese parsley, cilantro	Apiaceae	Whole herb infusion is taken orally to treat flatulence, bloating and cramps. ⁴¹ The whole plant decoction is taken orally to treat digestive problems. ⁴¹
<i>Dalbergia sissoo</i> Roxb. ex DC.	Sesam, Indian rosewood	Fabaceae	Bark and leaf juice is taken orally to treat diarrhoea. ^{37,39}
<i>Dalbergia mimosella</i> (Blanco) Prain	Goraksha	Fabaceae	Bark decoction is used orally to treat dyspepsia. ⁴²
<i>Desmostachya</i> <i>bipinnata</i> Linn. Stapf	Kusha, Darbha	Poaceae	Roots decoction is taken orally treat dysentery and diarrhoea. ⁴³
<i>Pleurolobus</i> <i>gangeticus</i> (L.) J.St.- Hil. ex H.Ohashi and K.Ohashi	Shalparni, Salvan	Fabaceae	Leaves, roots and whole plant decoctions are taken orally to treat diarrhoea and dysentery. ⁴⁴ Roots are crushed and mixed with ginger and taken orally with water to treat dysentery. ³²
<i>Phyllodium</i> <i>pulchellum</i> (L.) Desv.	Birsa, Chapos	Fabaceae	Whole plant paste is taken orally with water to treat dysentery and stomach pain. ³⁵
<i>Grona triflora</i> (L.) H.Ohashi and K.Ohashi	Herem ara	Fabaceae	Whole plant paste is taken orally to treat stomach pain. ³⁵ Cooked whole plant is taken orally to treat diarrhoea and dysentery. ⁴⁴ Whole plant with leaves of <i>Leucas cephalotes</i> (Roth.) Spreng. is made into a mixture and taken orally to treat diarrhoea and dysentery. ⁴⁴
<i>Dichrostachys cinerea</i> (L.) Wight and Arn.	Marud, Sickle bush, Viradru	Leguminosae	One tablespoon of leaf infusion is added to 50 mL goat's milk and administered orally twice a day for three days in the management of diarrhoea. ³⁹
<i>Dioscorea bulbifera</i> Linn.	Genti, potato yam	Dioscoreaceae	Root decoction is used to treat dysentery. ³³ Tubers are boiled and taken orally to treat abdominal pain. ⁴⁵ Bulbils are roasted and cooked as a vegetable and taken orally to cure dysentery. ⁴⁶
<i>Dioscorea pentaphylla</i> Linn.	Ram bahra, Paspotia, Baha	Dioscoreaceae	Tubers are boiled and eaten with salt to treat stomach pain, abdominal discomfort and dysentery. ⁴⁶
<i>Diospyros malabarica</i> (Desr.) Kostel.	Tinduka, Gab	Ebenaceae	Fruits are used in the treatment of diarrhoea, dysentery, and cholera. ⁴⁷
<i>Eclipta prostrata</i> Linn. Lour.	Bhringraj, Bhumiraj, Ink plant	Asteraceae	3-5 leaves are crushed and made into a paste. The paste is administered orally twice a day for 3 days to treat diarrhoea. ³⁹ The whole plant decoction is given orally thrice daily for 7 days or until diarrhoeal symptoms are resolved. ⁴⁸ Shoot juice and mustard oil are taken together orally to treat dysentery and diarrhoea. ⁴⁹
<i>Emblica officinalis</i> Linn.	Amla, Amalaki, Indian Gooseberry	Euphorbiaceae	Dry fruit powder is taken orally with water in the treatment of diarrhoea. ³⁷ Tender shoots are given orally with buttermilk to treat diarrhoea in children. Leaves are used in combination with fenugreek seeds as an infusion to treat chronic dysentery. ⁵⁰

Plant Species	Common Name	Family	Plant part used, Indications, Reference
<i>Euphorbia hirta</i> Linn.	Dudhi, Snakeweed, Asthma herb	Euphorbiaceae	A whole plant extract is taken orally to treat diarrhoea. ³⁷ Leaf juice with curd is taken orally to treat dysentery. ³³
<i>Ficus religiosa</i> Linn.	Ashvattha, Pipal, Jor	Moraceae	Three leaves are powdered with a small amount of jaggery (unrefined sugar) and taken orally twice daily to treat stomach pain. ³⁰ The formulation named “Pancha Valkala Kashaya”, contains <i>F. religiosa</i> bark, is used to treat dysentery. Leaf juice with honey is taken orally to treat diarrhoea. ⁵¹
<i>Ocimum tenuiflorum</i> Linn.	Tulsi, Holy Basil	Lamiaceae	Whole plant decoctions are used in the treatment of diarrhoea. ^{33,37}
<i>Phyllanthus niruri</i> Linn.	Bhumi amla, Chalmeri	Euphorbiaceae	Young shoots infusion is taken orally in the treatment of chronic dysentery. ⁵² The whole plant decoction is used to treat dysentery and dyspepsia. ⁵³ Infusions and decoctions of dried leaves are used orally to treat dysentery and diarrhoea. ⁵⁴
<i>Swertia chirayita</i> (Roxb. ex Fleming) H. Karst.	Chirata, Nelavebu, Indian Gentian	Gentianaceae	The whole plant decoction is taken orally to treat diarrhoea and dyspepsia. ⁵⁵ The whole plant is mixed with cardamom, turmeric and kutki (<i>Picrorhiza kurroa</i> Royle ex Benth.) is used in the treatment of GI infections. ⁵⁶
<i>Solanum nigrum</i> Linn.	Makoy, Black nightshade	Solanaceae	Berries are eaten to treat diarrhoea. ⁵⁷ Leaf juice or fresh leaves are cooked with onion bulbs and cumin seeds and taken orally to treat stomach ache and stomach ulcers. ⁵⁸
<i>Terminalia bellirica</i> (Gaertn.) Roxb.	Bibhitaki, Bahera, Beleric Myrobalan	Combretaceae	Mature and dried Fruit infusions are used orally to treat diarrhoea. ³⁷ Fruit pulp is taken orally to treat dysenteric diarrhoea. ⁵⁹
<i>Terminalia chebula</i> Retz.	Haritaki, Harad, Chebulic Myrobalan	Combretaceae	Dry fruit decoctions are taken orally to treat chronic diarrhoea. ^{32,60} 10 g of fruit powder is mixed in hot water and taken orally twice daily to treat dysentery until the disease is resolved. ³⁰
<i>Tinospora cordifolia</i> (Willd.) Miers ex Hook.f. and Thomson	Guduchi, giloe	Menispermaceae	Root infusion is taken orally to treat dysentery. ³³ Leaves, roots, and stem barks are used in equal amounts to make a decoction and taken orally three times a day to treat diarrhoea and dysentery. ³² Stem starch is taken orally with water for chronic diarrhoea and obstinate chronic dysentery. ⁶¹
<i>Vachellia nilotica</i> (L.) P.J.H. Hurter and Mabb.	Kikar, Babul	Fabaceae	Bark decoction is taken orally to treat diarrhoea. ³⁷ Pod powder is mixed with sugar or honey and taken orally to treat dysentery. ²⁹

to treat diarrhoea and other GI disorders and may improve the antioxidant profile within the GI tract.

Table 1 lists some of the most frequently used Ayurvedic medicines for the treatment of diarrhoea. Decoctions, infusion, juices, and powders are commonly used and are given orally with water, milk, or honey. Figure 3 contains photographs of several commonly used traditional Ayurvedic plants.

DISCUSSION

Ayurveda is a traditional medicine system that originated in South Asia approximately 3000 years ago and is widely still practiced today. It uses leaves, roots, barks and fruits (in the form of dried powder with water or their decoctions and infusions) in the treatment and management of multiple diseases, including diarrhoea. Interestingly, despite the extensive documentation of the use Ayurvedic of medicines to treat diarrhoea, many plants used in this system are yet to be rigorously studied and the efficacy

of many species are yet to be verified. Substantially more work is required to evaluate the potential of Ayurvedic medicine plants to prevent and treat diarrhoea. The aim of this review was to list some of the most important plants used in Ayurveda to treat diarrhoea, with a focus on GI bacterial pathogens. In this way, we highlight gaps in the literature, with the aim of focussing future studies in this field. Notably, many studies that have evaluated the activity of plant materials used in Ayurvedic medicine test extracts prepared using organic solvents, whereas the plant material may be used traditionally as aqueous decoctions or infusions. Whilst these studies are valuable as they are often designed to extract the widest complement of phytochemicals, they may not reflect the preparations as they are traditionally used. Studies are also required to test Ayurvedic plant species in the form that they are used traditionally.

Additionally, where plants used in Ayurvedic medicine have been evaluated for antibacterial activity, most studies have myopically



screened the individual components (or the multi-component preparation) without also evaluating the effects of combining the individual plant components in a mixture in various combinations. For example, triphala is multiple species herbal preparation that has a myriad of uses in Ayurveda, including for treating bacterial infections, and for treating diarrhoea. Triphala consists of the powdered fruits of three plant species (*Terminalia bellerica* (Gaertn.) Roxb., *Terminalia chebula* Retz. and *Embllica officinalis* (L.)) in equal ratios. The anti-diarrhoeal activity of triphala has been verified in laboratory studies.⁵⁹ Additionally, the antibacterial activity of *T. bellerica*,^{62,63} *Terminalia chebula*⁶⁴ and *Embllica officinalis*⁶⁵ have been verified individually against bacterial pathogens that cause diarrhoea. Interestingly, all of the individual plant preparations were good inhibitors of the growth of GI bacteria when tested alone. The reason that an Ayurveda practitioner's use of these plant materials in combination rather than separately is not fully understood. A recent study by our group tested extracts from these plants in various combinations and reported that combining the plants substantially potentiated the antibacterial activity of the preparation compared to the extracts when tested individually.¹⁰ Thus, these combinations not only enhance the antibacterial activity, they allow lower doses of the preparation to be used (thereby also reducing generation of new antibiotic-resistant strains), and may also increase the range of the bacteria that the therapy is useful against. We are unaware of other studies that have also evaluated anti-diarrhoeal Ayurvedic medicines in the same way and substantially more studies are required to evaluate other multi-component Ayurvedic preparations in this way.

Some studies that have examined the antibacterial and anti-diarrhoeal properties of Ayurvedic medicines have not tested the toxicity of these preparations in parallel with the antibacterial screening. Perhaps this is because the use of some of these medicines has been extensively documented for up to 3000 years, and it is generally assumed that they are safe. However, when tested in the laboratory, the plant materials are often prepared using different methods than they are when used traditionally. For example, whilst some traditional medicines are prepared as aqueous decoctions or infusions, screening studies often test extracts prepared using organic solvents. The preparation method may have profound effects on the phytochemical composition of the preparation, and therefore on the medicinal properties and toxicities of the preparations. Additional studies are required to re-evaluate the antibacterial properties of the plants listed herein, and to test the toxicity of those preparations in parallel with the bioactivity studies.

Similarly, the phytochemical composition of bioactive plant extracts should be reported in the same studies that evaluate their therapeutic properties. Ideally, the bioactive component(s) should also be identified by bioactivity driven separation studies, or by metabolomics comparison studies. Where the bioactive

constituents are known, their antibacterial mechanisms should also be determined, and their cross-reactivity and combinational effects with other drugs (both other plants used in Ayurveda, and allopathic medicines) should also be evaluated to ensure that the medicines are used safely and efficiently.

CONCLUSION

Plant species used in Ayurvedic medicine and the preparations that are used have potential in the treatment of diarrhoea and GI bacterial infections. However, many of these therapies are yet to be thoroughly evaluated for efficacy and safety. Substantially more pharmacognostic studies are required to better understand these therapies and to allow for the more widespread adoption to treat diarrhoea.

ACKNOWLEDGEMENT

The authors wish to thank Jasbir Singh Munday for supplying photographs of plants and plant materials.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

ABBREVIATIONS

AMR: Antimicrobial resistance; **GI:** Gastrointestinal; **GSH:** Reduced glutathione; **GSSG:** Oxidised glutathione; **MIC:** Minimum inhibitory concentration; **MRSA:** Methicillin-resistant *Staphylococcus aureus*; **PHF:** Polyherbal formulation; **ROS:** Reactive oxygen species; **WHO:** World Health Organization.

SUMMARY

- Ayurveda is one of the oldest recorded traditional healing systems still widely practiced.
- This study reviewed the principles of Ayurveda and their foundation in healing.
- 39 plant species that are used in Ayurveda to treat gastrointestinal complaints, including infections, are highlighted.

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Cite this article: Tiwana G, Cock IE, Cheesman MJ. A Review of Ayurvedic Principles and the Use of Ayurvedic Plants to Control Diarrhoea and Gastrointestinal Infections. *Pharmacognosy Communications.* 2023;13(4):152-62.