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REVIEW

Unraveling the treasure trove of phytochemicals in mitigating the *Salmonella enterica* infection

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Abstract

Foodborne diseases triggered by various infectious micro-organisms are contributing significantly to the global disease burden as well as to increasing mortality rates. *Salmonella enterica* belongs to the most prevalent form of bacteria accountable for significant burden of foodborne illness across the globe. The conventional therapeutic approach to cater to *Salmonella enterica*–based infections relies on antibiotic therapy, but the rapid emergence of the antibiotic resistance strains of *Salmonella* sp. necessitates the development of alternative treatment and prevention strategies. In light of this growing concern, the scientific community is rigorously exploring novel phytochemicals harnessed from medicinally important plants as a promising approach to curb *Salmonella enterica* infections. A variety of phytochemicals belonging to alkaloids, phenols, flavonoid, and terpene classes are reported to exhibit their inhibitory activity against bacterial cell communication, membrane proteins, efflux pumps, and biofilm formation among drug resistant *Salmonella strains*. The present review article delves to discuss the emergence of antibiotic resistance among *Salmonella enterica* strains, various plant sources, identification of phytochemicals, and the current state of research on the use of phytochemicals as antimicrobial agents against *Salmonella enterica*, shedding light on the promising potential of phytochemicals in the fight against this pathogen.

Keywords *Salmonella enterica* · Antimicrobial resistance · Multi-drug resistant strains · Phytochemicals · Antimicrobial activity

Introduction

Enteric fever, also known as typhoid fever, primarily attributed to *Salmonella enterica* and *Salmonella* typhimurium species is recognized as a potentially serious foodborne illness across the globe (Almuzaini 2023). *Salmonella enterica* infection can lead to a variety of symptoms, from minor gastroenteritis to severe systemic ailments, and can have life-threatening consequences (Borges et al. 2013). As per Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) 2017, it is estimated that 93.8 million people suffered by *Salmonella* infections and approximately 1.55 Lac deaths incurred every year worldwide (Balasubramanian et al. 2019). The ever-increasing incidence rate of foodborne diseases in developing nations is a profoundly concerning problem that requires immediate contemplation (Mandal et al. 2014). In Indian context, the incidence and mortality rates associated to enteric fever are increasing significantly every year, with a mortality rate ranging from 10 to 30%. According to National Incidence of Enteric Fever database indicates that approximately 4.5 million individuals are afflicted by enteric fever annually, resulting in an estimated 8930 deaths (Kumar et al. 2022). Such alarming situation imposes the critical need for immediate and focused attention to address this persistent communal health concern.

To combat the *Salmonella enterica* infections, first-line choice antibiotics included ampicillin, chloramphenicol, and trimethoprim-sulfamethoxazole. The upsurge in *Salmonella* infection has accorded an uptick in uncontrolled antibiotic administration which led to the emergence of resistance to antimicrobial treatments in *Salmonella enterica* (Khameneh et al. 2019; Elmongy et al. 2022). Rapid emergence of multi-drug resistant (MDR) strains of *S. enterica* led to

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the utilization of fluoroquinolones class of antibiotics, viz., ofloxacin, levofloxacin, and ciprofloxacin (Browne et al. 2020). With the recent advent of fluoroquinolone-resistant *Salmonella* strains, third generation cephalosporin and azithromycin are the recommended choice of antibiotics to combat *Salmonella enterica* infections nowadays (Nair et al. 2018). Owing to the upsurge of MDR/XDR strains of *Salmonella enterica* and the significant peril it poses to public health, the World Health Organization (WHO) has prioritized the advancement of innovative antibiotics with much wider spectrum of activity (Elmongy et al. 2022).

Since many decades, medicinal plants are well known for their therapeutic properties and being employed as herbal remedies in the management of a wide array of infectious diseases. Out of about 17,000 higher class Indian plants, 7500 plants exhibit medicinal attributes towards various lifestyle and infectious disorders (Ashraf et al. 2023). Medicinal plants are reported to be reservoir of plethora of bioactive phytochemicals with diverse structural and functional attributes and have been an integral component of traditional medicines. Protuberant examples of bioactive compounds harnessed from medicinal plants encompass alkaloids, terpenoids, coumarins, flavonoids, nitrogen-containing compounds, organosulfur compounds, and phenolics (Al-Abd et al. 2015), which are being employed against various drug-resistant bacterial strains like *Escherichia coli*, *Salmonella typhimurium*, *Salmonella enterica*, *Pseudomonas aeruginosa*, *Klebsiella pneumonia*, and *Staphylococcus aureus*. Much of the evidence validates the significant contribution of phytochemicals obtained from the extracts of medicinal plants (Wang et al. 2020) as valuable source of anti-cancer, antioxidant, antidiabetic, immunosuppressive, antifungal, anti-inflammatory, antimalarial, antibacterial, anti-fever, and antiviral agents (Borges et al. 2016). Therefore, continual efforts are being put forth by researchers to discover new phytochemicals obtained from medicinal plants, so that new and better drugs can be developed to cater the recurrent and frequent episodes of infections from multi-drug resistant strains of *Salmonella enterica* (Mehta et al. 2016).

Emergence of antibiotic resistance

Salmonellosis is considered to be the most common infectious disease among range of foodborne illness diseases worldwide. The extensive utilization of range of antimicrobial compounds in typhoid and paratyphoid has led to the development of resistant strains of *Salmonella*, thereby limiting treatment options and increasing the prevalence of *Salmonella* infection. The evolution of MDR strains of *Salmonella* began in the 1980s (Eng et al. 2015) due to multiple acquisitions of plasmids. Compared to previous years, the MDR strains of *S. enterica* were 0.41% in 2005, which increased to 1.71% in 2019 (Pietsch et al. 2021). Centers for Disease Control and Prevention (CDC) detected antimicrobial resistance to various antibiotics such as ampicillin, chloramphenicol, streptomycin, tetracycline, fluoroquinolone, third-generation cephalosporin, and trimethoprim-sulfamethoxazole, used against *Salmonella* sp. infection by detecting the existence of resistance genes by employing polymerase chain reaction (PCR) (Pinto et al. 2010). The *Salmonella enterica* and *Salmonella* Typhi clinical strains conferring resistance to chloramphenicol, ampicillin, and trimethoprim–sulfamethoxazole were categorized as multi-drug resistant (MDR) strains. However, the isolates that were recognized as MDR and also displayed resistance towards fluoroquinolone-based antibiotics and third-generation cephalosporins were classified as extensively drug resistant (XDR). The major genes accountable for conversing resistance towards third-generation class of antibiotics, viz., cephalosporins, were found to be linked with the presence of AmpC β-lactamase genes such as bla_{CMY-2} (Lynee et al. 2008), bla_{ACC-1}, and extended-spectrum β-lactamase (ESBL) gene bla_{SHV-12}, while azithromycin resistance was related with the existence of *acrB* gene (Table 1).

In 2017, the World Health Organization described fluoroquinolone-resistant *S. enterica* as a form of plasmid-mediated quinolone resistance (PMQR) (Chang et al. 2021) indicating low levels of quinolone susceptibility with mutations in DNA gyrase (topoisomerase II) and topoisomerase IV in *Salmonella*. It results from a double mutation in *gyr*A gene and a single mutation in *par*C gene. The resistance to ciprofloxacin in *Salmonella* is determined by genes, viz., *qnr*A, *qnr*B, *qnr*C, *qnr*D, *qnr*S, *aac(6')lb-cr*, and *oqx*AB (Jiang et al 2014; Lin et al. 2015). Clinical and Laboratory Standards Institute (CLSI) report in 2015 showed that azithromycin resistance in *Salmonella enterica* was due to mutations in *acr*R, *rpl*D, and *rpl*V genes (Sajib et al. 2021). In third-generation cephalosporins, the main cause of *Salmonella*-resistant strains was the production of extended spectrum beta lactamase ($bla_{CTX-M-1}$, $bla_{CTX-M-14}$, and $bla_{CTX-M-65}$) or AmpC beta lactamase (Pietsch et al. 2021).

Phytochemicals as a remedial approach

Since antiquity, medicinal plants have been utilized as sources of traditional medicine in Unani Hakim and Indian Vaids (Sen & Chakraborty 2016). Plants have been an indispensable source in providing food additives and industrial biochemicals and aiding in the treatment of infectious ailments as well as contributing significantly in meeting the daily life needs. As per report of WHO, approximately 80% of the drugs offered for the management of range of infectious and life style diseases are derived from plants being less immunogenic, more efficient, and of lower cost also

Table 1 Antibiotic resistance gene (s) with primer pair, size reported in *Salmonella* species

S. no	Name of antibiotic	Antibiotic resistance gene	Primer pair	Size of amplicon	Resistant micro-organism	Reference
	Ampicillin	bla_{TEM}	5′-ATGAGTATTCAA CATTTCCG-3′ 5′-ACCAATGCTTAA TCAGTGAG-3′	859 bp	*Salmonella* sp.	Aarestrup et al. (2003)
	Chloramphenicol	*cat A1*	5′-CGCCTGATGAAT GCTCATCCG-3′ 5′-CCTGCCACTCAT CGCAGTAC-3′	508 bp	*Salmonella* typhimu-rium DT104	Aarestrup et al. (2003); Mossoro-Kpinde et al. (2015)
	Neomycin	*aphA-2*	5′-GCTATTCGGCTA TGACTGGGC-3′ 5′-CCACCATGATAT TCGGCAAGC-3′	401 bp	*Salmonella enterica* serovar typhimurium *DT104*	Aarestrup et al. (2003)
	Streptomycin	*strA*	5′-CCAATCGCAGAT AGAAGGC-3′ 5′-CTTGGTGATAAC GGCAATTC-3′	548 bp	*Salmonella* sp.	Aarestrup et al. (2003); Mulvey et al. (2006)
		aadA	5′-ATCCTTCGGCGC GATTTTG-3′ 5′-GCAGCGCAA TGACATTCTTG-3′	528 bp		
	Tetracycline	*tet(A)*	5′- GTGAAACCC AACATACCCC-3' 5′-GAAGGCAAG CAGGATGTAG-3'	888 bp	*S. enterica*	Glenn et al. (2011)
		tet(B)	5′-CCTTATCATGCC AGTCTTGC-3′ 5′-ACTGCCGTTTTT TCGCC-3′	774 bp	*S. enterica*	Aarestrup et al. (2003)
		tet(C)	5′-CTT GAG AGC CTT CAA CCC AG3′ 5′-ATG GTC GTC ATC TAC CTG CC-3′	418	*Salmonella enterica* s erovars	Khoshbakht et al. (2018)
		tet(G)	5′-GCTCGGTGGTAT CTCTGCTC-3′ 5′-AGCAACAGA ATCGGGAAC AC-3′	468	*Salmonella infantis*	Dahshan et al. (2010)
	Fluoroquinolone	*gyrA* gene	5′ATGAGCGACCTT GCGAGAGAAATT ACACCG3′ 5′TTCCATCAGCCC TTCAATGCTGAT GTCTTC-3′	630 bp	*S.* typhimurium	Brown et al. (1996)
		parC gene	5′-ATGAGCGATATG GCAGAGCG-3′ 5′-TGACCGAGTTCG CTTAACAG-3′	270 bp	*S. enterica*	Eaves et al. (2004)

Table 1 (continued)

S. no	Name of antibiotic	Antibiotic resistance gene	Primer pair	Size of amplicon	Resistant micro-organism	Reference
	Ciprofloxacin	*qnrA*	F: ATTTCTCACGCC AGGATTTG R: GATCGGCAA AGGTTAGGTCA	516 bp	*Salmonella enterica* serotype typhi	Ramachandran et al. (2017)
		qnrB	F: GATCGTGAA AGCCAGAAAGG R: ACGATGCCTGGT AGTTGTCC	469 bp		Ramachandran et al. (2017)
		qnrC	F: GCAGAATTC AGGGGTGTGAT R: AACTGCTCC AAAAGCTGCTC	118 bp		Ciesielczuk et al. (2013)
		qnrD	F5′CGAGATCAATTT ACGGGGAATA3′ R 5′-AACAAGCTG AAGCGCCTG-3′	660 bp	*S. enterica*	Cavaco et al. (2009)
		qnrS	F: ACGACATTCGTC AACTGCAA R:TAAATTGGCACC CTGTAGGC	417 bp	*Salmonella enterica* serotype typhi	Ramachandran et al. (2017)
		aac(6′)lb-cr	F: TTGCGATGCTCT ATGAGTGGCTA R: CTCGAATGC CTGGCGTGTTT	584 bp	*Salmonella enterica* serotype typhimu-rium	Li et al. (2013)
		oqxAB Plasmid-mediated quinolone resistance (PMQR) determinants	**oqxA** F: CGAACCGCA CCGATAAATTAG TCCATACCA R: CCTCGCCAA CCAGGCCAATCT CCA **oqxB** F: CGCCAACCC GAAAGTGATTGC CGAGAC R: TACCAGCAC CACCAGCACTAC CGCCTCC	1175 bp 3152 bp	*Salmonella enterica* serotype typhimu-rium	Li et al. (2013)
	Azithromycin	*acrR*	F:5′-GGTCCTTAA ACCCATTGCTG-3′ R:5′-ACAGAATAG CGACACAGA AA-3′	816 bp	*Salmonella enterica* serotype *Typhi*	Sharma et al. (2013)
		rplD *rplV*	5′-TGAAGGCGT AAGGGGATA GCA-3′ 5′-TCAGCAGA CGT TCTTCACGAA-3′ 5′-GAAATAAGG TAG GAGGAA GAG-3′ (5′-CCATTGCTA GTCTCCAGA GTC-3′)	606 bp 333 bp	*S. enterica*	Gunell et al. (2010)

Table 1 (continued)

S. no	Name of antibiotic	Antibiotic resistance gene	Primer pair	Size of amplicon	Resistant micro-organism	Reference
	Cephalosporins	$bla_{CTX\text{-}M\text{-}1}$	5′-AGAATAAGG AATCCCATGGTT 5′-GCAAGACCT CAACCTTTTCC	850 bp	*Salmonella* serogroup	Salimian Rizi et al. (2015)
		$bla_{CTX\text{-}M\text{-}14}$	5′-ATG ATG ACT CAG AGC ATT CG-3′ 5′-TGG GTT ACG ATT TTC GCC GC-3′	690 bp	*Salmonella enterica* serovars	Eller et al. (2013)
		AmpC beta lactamase	5′-TCTGCTGCTGAC AGCCTCT-3′ 5′-CTCGACACGGAC AGGGTTAG-3′	875 bp	*Salmonella enterica* serovars	Eller et al. (2013)

(Sharma and Alam 2022). Bioactive organic substances found in plants are synthesized from the primary or secondary metabolism of living organisms, which are chemically and taxonomically diverse (Yadav and Agarwala 2011). Among these substances, tannins, alkaloids, flavonoids, phenolic, carbohydrates, steroids, glycosides, and saponins are prominent, whose are obtained from various parts of medicinal plants like bark, leaves, stem, roots, flowers, fruits, and seeds. They are used in human medicine, veterinary medicine, scientific research, and many other fields (Anand et al. 2022). Terpenoids and tannins are used in analgesic and anti-inflammatory activities; saponins are used in the treatment of fungal, bacterial, and yeast infections; flavonoids are used in the treatment of allergy, inflammation, platelet aggregation, pathogens, ulcers, hepatoxins, viruses, and tumors; and cardiac glycosides are used in treatment of heart failure (Yadav and Agarwala 2011). Many plant-derived bioactives have shown potential as antipyretic, diuretic, analgesic, anthelmintic, antiseptic, antitumor, and anti-inflammatory agents (Table 2).

Many studies reported the whole plant as well as different plant parts, viz., shoot, root, seed, leaves, bark, flowers, and inflorescence of various medicinal plants belonging to Fabaceae, Simaroubaceae, Scrophulariaceae, and Lythraceae family possess bioactive compounds to be exploited against treatment of fever, cough, cold, malaria, piles, etc. (Arya et al. 2022). Phenolic compounds extracted from leaf of *Justicia zeylanica* and leaf, bark, and pods of *Acacia nilotica* were observed to exhibit antimicrobial activity towards *S. aureus* and *E. coli*. However, *J. zeylanica* was also active against *B. cereus*, *L. monocytogenes*, *S.* typhimurium, *Y. enterocolitica*, *V. cholera*, and *S. flexneri* (Aggarwal et al. 2022). Further, bioactive compounds harnessed from *Acacia nilotica* exhibited antimicrobial potential against *M. tuberculosis*, *P. aeruginosa*, and *S. enterica* (Sadiq et al. 2015). Numerous previous studies have documented the role of novel phytochemicals with great antimicrobial spectrum against range of infectious micro-organisms, viz., *Pseudomonas aeruginosa*, *P. falciparum*, *B. subtilis*, *S. aureus*, *S.* Typhi, *C. albicans*, *Aspergillus niger*, *P. vulgaris*, *S. pyogenes*, and *K. aerogenes*, thereby validating the immense chemical diversity with bioactive/therapeutic potential of medicinal plants (Table 3).

Anti-*salmonella* potential of phytochemicals

In catering *Salmonella enterica* infection, many novel bioactive compounds have been harnessed from medicinal plants with much increased efficacy and potency. Ethanolic and aqueous extracts of *Khaya senegalensis* exhibited promising anti-salmonella activity at different concentrations ranging from 50 to 500 mg/mL with zone of inhibition ranging from 14 to 27 mm (Ugoh et al. 2014). A previous study detailing the in vivo anti-salmonella activity of aqueous extract of *Euphorbia prostrata* also reported the considerable decline in viable no. of *Salmonella typhimurium* recovered from the feces after 8–10 days (Tala et al. 2015). Aqueous extracts of the leaf, stem, and root of *Abrus precatorius* inhabiting Kwara State, Nigeria, were reported to produce mixture of phytochemicals comprising different concentrations of tannin, saponins, alkaloids, flavonoids, terpenoids, steroids, and phenols in all plant parts with antibacterial activity against *S.* Typhi with MIC of 40 mg/mL (Sunday et al. 2016). There exist many reports documenting the antibacterial action of essential oil purified from various medicinal plants (Oussalah et al. 2007). Miladi et al. (2016) observed anti-salmonella activity of essential oils of three Mediterranean plants, viz., *Satureja montana* L, *Thymus vulgaris* L., and *Rosmarinus officinalis* L., belonging to Lamiaceae

Table 2 Medicinal plants and their parts with therapeutic potential

Family	Plant's species	Plant parts	Traditional uses	References
Fabaceae	*Aeschynomene aspera*	Shoots	Treat cold, fever and cough, increase semen consistency	Arya et al. (2022)
	Abrus precatorius Linn	Root	Used in fever	Saini et al. (2019)
	Trigonella foenum	Seeds	Used as an antipyretic agent	Saini et al. (2019)
Simaroubaceae	*Ailanthus excelsa* Roxb	Leaves, bark	Antimalarial	Saini et al. (2019)
Scrophulariaceae	*Lindernia anagallis*	Whole plant	Asthma, gonorrhea	Arya et al. (2022)
Lythraceae	*Rotala indica*	Flower, leaf	Antipyretic, antiswelling	Arya et al. (2022)
	Rotala rotundifolia	Whole plant	Cold, fever, cough, diuresis, gonorrhea, menstrual cramps, piles, HepA2 cells production, suppression of HBsAg	Arya et al. (2022)
Liliaceae	*Aloe vera* (Linn.) Barm	Pulp juice	Fever	Saini et al. (2019)
Lamiaceae	*Ocimum sanctum* Linn	Whole plant	Bronchitis, asthma, malaria, diarrhea, dysentery, skin diseases, arthritis	Saini et al. (2019)
Caesalpiniaceae	*Cassia fistula* Linn	Bark, pods	Fever	Saini et al. (2019)
Asteraceae	*Achillea millefolium*	Flowers, whole plant	Sharma and Alam (2022)	Sharma and Alam (2022)
	Ageratum conyzoides	Whole plant	Stimulant, analgesic, fever, good source of vitamin K, rheumatism, anthelmintic dermatitis	Arya et al. (2022)
	Blumea lacera	Leaves	Stimulant, diuretic, antispasmodic, astringent	Sharma and Alam (2022)
	Helianthus annuus	Whole plant	Diuretic, coughs, colds, antimalarial, bronchial infection	Sharma and Alam (2022)
	Parthenium hysterophorus	Whole plant	Skin problem, rheumatism, diarrhea, antimalarial, urinary tract infections, neural problems, dysentery	Sharma and Alam (2022)
	Taraxacum officinale	Whole plant	Diuretic, tonic, stomachic, hepatic stimulant, menopause, antidiabetic	Sharma and Alam (2022)
	Tagetes erecta	Leaves, flowers	Antiseptic, kidney problems, muscular pain, piles	Sharma and Alam (2022)
	Tridax procumbens	Whole plant	Hemostatic, antiseptic, skin diseases, ulcer, wounds	Sharma and Alam (2022)
	Vernonia cinerea	Whole plant	Diabetes, kidney disorders and stones, insomnia, anhidrosis, rheumatism	Sharma and Alam (2022)
	Bellis perennis	Whole plant	Bruises, bone fractured, wounds, and eye and skin problems	Sharma and Alam (2022)
	Caesulia axillaris	Whole plant	Healing wounds	Arya et al. (2022)
Acanthaceae	*Hygrophila auriculata*	Whole plant	Diuretic, hydropsy, menstruation, stomachache	Arya et al. (2022)
	Hygrophila polysperma	Leaves, seeds	Relieves cardiac ailments, healing kidney disorders, skin problems, and swelling	Arya et al. (2022)
Araceae	*Cryptocoryne retrospiralis*	Fresh tubers	Antiemetic, boils, burns, and vomiting during pregnancy	Arya et al. (2022)
	Lagenandra ovata	Whole plant	Kidney disorders, skin problems and swelling, antimutagenic, antitumor, pain killer	Arya et al. (2022)
Cyperaceae	*Cyperus rotundus* Linn	Root	Diarrhea, diabetes, pyresis, inflammation, malaria, and stomach and bowel disorders	Saini et al. (2019)
	Cyperus haspan	Rhizome	Fever, cough	Arya et al. (2022)
Poaceae	*Coix aquatica*	Roots	Urination and menstrual problems	Arya et al. (2022)
Polygonaceae	*Polygonum barbatum*	Leaves, roots, seeds	Wound bleeding, colic pain, ulcers, migraine	Arya et al. (2022)
Pontederiaceae	*Monochoria vaginalis*	Leaves, flowers	Asthma, coughs, stomach, toothache, swelling, liver disorders	Arya et al. (2022)

Table 2 (continued)

Family	Plant's species	Plant parts	Traditional uses	References
Meliaceae	*Azadirachta indica*	Leaves	Malaria	Saini et al. (2019)
Moraceae	*Ficus religiosa* Linn	Fruit juice	Fever	Saini et al. (2019)
Menispermaceae	*Tinospora cordifolia*	Stem	Fever	Saini et al. (2019)
Menyanthaceae	*Nymphoides indica*	Whole plant	Fever, headache, rheumatism, scabies disorders	Arya et al. (2022)
Onagraceae	*Ludwigia octovalvis*	Whole plant	Treat body ache, boil, diarrhea, fever, flatulence, heal dermatitis, toxemia, ulcer	Arya et al. (2022)
Nymphaeaceae	*Nymphaea pubescens*	Rhizome, roots	Blood dysentery, dyspepsia, jaundice, leucorrhoea, menorrhagia, piles	Arya et al. (2022)
	Nymphaea stellata	Leaves	Stomach disorders	Arya et al. (2022)
Nyctaginaceae	*Boerhavia diffusa* Linn	Whole plant	Antipyretic	Saini et al. (2019)
Hydrocharitaceae	*Vallisneria spiralis*	Leaves	Leucorrhoea, stomachache	Arya et al. (2022)
Burseraceae	*Boswellia serrata* Roxb	Flower	Fever	Saini et al. (2019)
Brassicaceae	*Sisymbrium irio* Linn	Leaf, seed, flower	Cough, chest congestion, rheumatism, detoxify the liver and spleen, swelling, and wounds	Saini et al. (2019)
Apocynaceae	*Holarrhena antidysenterica* Linn	Leaf	Fever	Saini et al. (2019)
Capparaceae	*Capparis decidua*	Root	Fever	Saini et al. (2019)
Cleomaceae	*Cleome viscosa* Linn	Leaf	Rheumatic arthritis, hypertension, malaria, neurasthenia, wound healing	Saini et al. (2019)
Convolvulaceae	*Evolvulus alsinoides* Linn	Whole plant	Fever	Saini et al. (2019)
Gentianaceae	*Enicostema axillare*	Leaf	Malaria	Saini et al. (2019)
Verbenaceae	*Vitex negundo* Linn	Flower	Fever	Saini et al. (2019)

family. The study revealed that *S. montana* L. and *T. vulgaris* L. essential oils possess remarkable anti-biofilm, anti-adhesive, and bactericidal properties. Furthermore, essential oil and its synergistic effect along with antibiotics were also reported in multiple scientific studies. Essential oil and methanolic extracts of *Nigella sativa* exhibited potent antibacterial action towards resistant strains of *S. enterica* with MIC value $\geq 1000.0 \pm 322.7$ µg/mL and $\geq 562.5 \pm 384.1$ µg/mL, respectively (Ashraf et al. 2018). A study documenting the bactericidal potential of ethanolic extract of *Punica granatum* L. (different parts—peels, seeds, juice, and flowers) against *Salmonella enterica* serovars Kentucky and Enteritidis isolated from chicken meat was carried out. The findings revealed that the most compelling antibacterial effect against *Salmonella* strains was exerted by the ethanolic extract of peels, demonstrating MIC values between 10.75 and 12.5 mg/mL (Wafa et al. 2017). Mahlangu and coworkers (2017) reported the potent anti-salmonella activity of dichloromethane, methanol, and acetone leaf extracts of an African medicinally important plant, viz., *Albizia gummifera* against *Salmonella typhimurium*, *S.* Enteritidis, *S.* Dublin, and *S. gallinarum*, with MIC and MBC values ranging between 0.125–1 mg/mL and 0.25 to > 2.00 mg/mL, respectively. In last decade, multiple studies documenting the antibacterial potential of different solvent extracts from medicinal plants, viz., ethyl acetate extract of *Streblus asper* against *S. paratyphi* (zone of inhibition, 38 mm) with MIC value of 12.50 mg/mL (Arulmozhi et al. 2018) and methanolic, ethyl acetate extracts of North-Western Himalaya medicinal plants (*Pistacia integerrima*, *Ocimum sanctum*, *Centella asiatica*, *Momordica charantia*, *Zingiber officinale*, and *Withania somnifera*) in combination with ciprofloxacin and tetracycline, exhibited promising synergistic antimicrobial activity with GIIs of 0.61–1.32 and GIIs of 0.56–1.35, respectively (Mehta et al. 2022).

The study carried out by Mbock et al. (2020) demonstrated that the hydroethanolic extract of *Detarium microcarpum* root bark as well as the purified compound rhinocerotinoic acid exhibited promising anti-salmonella activity in infected animals with an effective dose (ED_{50}) of 75 mg/kg. Besides conventional screening and evaluation methods, GC–MS analysis coupled with molecular docking and ADMET profiling of methanolic extract of *Psidium guajava* displayed that the four compounds, namely, (4-[5-(4-pyridinyl)-1,2,4-oxadiazol-3-yl]-1,2,5-Oxadiazol-3-amine; Cholesta-3,5-diene; 2-hydroxy-Cyclopentadecanone; Oxane-2,4-dione, 6-(4-methoxypheny l)-3,3,5,5-tetramethyl-), exhibited better binding affinity ranging between − 6.6 and − 7.4 kcal/mol with DNA gyrase subunit A of *S. typhi* as compared to standard drug ciprofloxacin (− 6.4 kcal/mol) (Adetutu et al. 2021). Another investigation focused on screening extracts of *Adhatoda vasica*, *Amaranthus hybridus*, and *Aloe barbadensis*

Table 3 Antibacterial potential of various classes/phytochemicals harnessed from different parts of medicinal plants

Plant's species	Plant's parts	Phytochemicals	Antimicrobial properties	References
Mitragyna parvifolia	Leaf, bark	Isobutanoic acid, 2-ethylhexyl ester, 4-methyl mannose, mitraphylline, isomitraphylline, 1,2-Hydrazine dicarboxylic acid, diethyl ester, α,α-dimethyl mucconic acid, isobutanoic acid, 2-ethylhexyl ester, α-D-glucopyranoside, α-D-glucopyranosyl	*Escherichia coli*, *Pseudomonas aeruginosa*, *Bacillus subtilis*	Vasmatkar et al. (2014)
Phyllanthus urinaria	Whole plant parts	Lignans (phyllanthin, phyltetralin), flavonoids (quercetin 7-methyl ether, quercetin 3-O-β-D-glucoside, rhamnocitrin), phenolics (trimethyl-3,4-dehydrochebulate, methyl brevifolincar boxylate), steroids (β-sitosterol-3-O-β-d-glucopyranoside)	*Helicobacter pylori*, *Plasmodium falciparum*, *Salmonella* Typhi	Geethangili and Ding (2018)
Phyllanthus emblica	Leaf, fruits	Alkaloids, phenolic contents, tannins, lignin, saponins, flavonoids, terpenoids, quinones, anthraquinones, DPPH, sterols, proteins, glyceroids	*Staphylococcus aureus*, *Bacillus subtilis*, *Pseudomonas aeruginosa*, *Escherichia coli*, *Salmonella enteritidis*	Nath and Dhivy (2019)
Chlorophytum borivilianum	Leaf, stems, root	Alkaloids, glycosides, saponin, glycosides, steroids (stigmasterol, hecogenin), phenols, tannins, Ag^{+} ions	*Staphylococcus aureus*, *Bacillus subtilis*, *Bacillus cereus*, *Escherichia coli*, *Candida albicans*, *Pseudomonas aeruginosa*, *Aspergillus niger*, *Salmonella enterica*	Chowdhury et al. (2021)
Chlorophytum tuberosum	Root, tubers	8-methyl-4' methoxy-7-O-α-L-rhahmnopyranoside bis isoflavone, sitosterol, stigmasterol	*Escherichia coli*, *Bacillus subtilis*, *Rhizopus stolonifer*, *Aspergillus niger*, *Penicillium expansum*, *Salmonella* Typhi	Bhat et al. (2022)
Calotropis procera	Twigs, leaf, flower, root	Proceragenin, afrogenin, 12β-hydroxy carpogenin, 12β-hydroxy coroglaucigenin, calactin, calotoxin, afroside, uscharin	*Micrococcus luteus*, *Proteus mirabilis*, *Salmonella gallinarum*, *Salmonella* Typhi, *Proteus vulgaris*, *Streptococcus pyogenes*, *Aspergillus niger*, *Candida albicans*, *Trichophyton rubrum*, *Mycobacterium bovis*	Amini et al. (2021)
Dipterocarpus turbinatus	Stem, bark, root, leaf	B-sitosterol, bergenin, dipterocarpol, Asiatic acid, borneol	*Escherichia coli*, *Bacillus cereus*, *Staphylococcus aureus*, *Bacillus azotoformans*, *Salmonella* Typhi, *Pseudomonas aeruginosa*	Aslam et al. (2015)
Thevetia neriifolia	Seeds, root, fruit, leaf	Tannins, flavonoids, coumarins, quinones, carotenoids, saponins, alkaloids, terpenes	*Escherichia coli*, *Proteus vulgaris*, *Pseudomonas aeruginosa*, *Salmonella* Typhi, *Vibrio vulnificus*, *Aspergillus niger*, *Aspergillus fumigatus*, *Candida albicans*	Gangwar et al. (2013)

Table 3 (continued)

Plant's species	Plant's parts	Phytochemicals	Antimicrobial properties	References
Tephrosia purpurea	Leaf, root	Tephrosin, deguelin, isotephrosin, rotenone, glycoside osyritin, β-sitosterol, rutin, lupeol	*Staphylococcus aureus*, *Escherichia coli*, *Aspergillus niger*, *Alternaria, Salmonella* Typhi	Egharevba et al. (2019)
Solanum surattense	Leaf, fruit, seed, root	Solamargine, solasurine, solasonine, ascorbic acid, torvoside K, torvoside L, khasianine, aculeatiside A, carpesterol, caffeic acid, triterpinoids, solanocarpine, solamorgine, solanocarpidine, esculentin, aesculin, campesterol, daucosterol, stigmasterol, cycloortanol, lupeol, diosgenine	*Staphylococcus aureus*, *Streptococcus species*, *Vibrio cholera*, *Pseudomonas aeruginosa*, *Salmonella* Typhi, *Shigella dysenteriae*, *Escherichia coli*, *Micrococcus luteus*, *Aspergillus niger*, *Aspergillus flavus*, *Aspergillus fumigates*, *Trichoderma viride*, *Rhizopus oryzae*, *Plasmodium falciparum*	Kumar (2021)
Pithecellobium dulce	Root, seed, leaf	D-turanose, inositol derivatives, hexadecanoic acid, dihydroxyacetone, D-glucohexodialdose, 2-deoxy-galactopyranose, ribitol, D-mannose, altronic acid, indole-1-acetic acid, octadecanoic acid	*Staphylococcus aureus*, *Klebsiella pneumoniae*, *Enterobacter aerogenes*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Acinetobacter baumannii*, *Salmonella* Typhimurium	Aldarhami et al. (2023)
Jatropha gossypifolia	Leaf, stem, root, latex	Phytol, germacrene, linalool, limonene, α-copaene, α-terpinene, α-aromadendrene, lanosterol, humulene, linoleic acid, heptadecanoic acid, 2,6-di-butyl-p-cresol	*Staphylococcus aureus*, *Escherichia coli*, *Enterococcus faecium*, *Salmonella* Typhimurium	Okoh et al. (2016)
Holoptelea integrifolia	Leaf, stem, bark	Eicosanoids, prostaglandins, leukotrienes, DPPH, friendlin, holoptelin-A and B, stigmasterol, botulin, β-amyrin, epifriedlin, hexa and octacosanol, betulinic acid	*Bacillus subtilis*, *Bacillus cerculences*, *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Candida albicans*, *Klebsiella pneumoniae*, *Aspergillus niger*, *Saccharomyces cerevisiae*, *Candida krusei*, *Candida tropicana*, *Salmonella enterica*, *Salmonella* Typhimurium	Reddy et al. (2008)
Lantana camara	Whole plant parts	Dipentene, geraniol, linalo-ol, cineol, eugenol, citral, furfural, phellandrone, α-terpeneol, α-phellandrene, camaryolic acid, methyl-camaralate, camangeloyl acid	*Escherichia coli*, *Bacillus subtilis*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Vibrio cholera*, *Alcaligenes faecalis*, *Klebsiella pneumoniae*, *Candida albicans*, *S. cerevisiae*, *Aspergillus niger*, *Aspergillus flavus*, *Sclerotium rolfsii*, *Salmonella* Typhi	Saraf et al. (2011)
Saraca asoca	Bark, stem, root, flower, seed	Epicatechin, procyanidin p2, catechin, leucopelar gonidin, leucocyanidin, P&Y sitosterols, nudiposide, icariside E_3, lyoniside, 5-diglucoside, palmitic acid, stearic acid, pelargonidin-3, quercetin	*Bacillus subtilis*, *Escherichia coli*, *Salmonella typhosa*, *Salmonella viballerup*, *Staphylococcus aureus*, *Shigella boydii*, *Vibrio cholera*, *Shigella dysenteriae*, *Klebsiella aerogenes*, *Proteus vulgaris*, *Salmonella enteritis*, *Salmonella* Typhimurium	Pradhan et al. (2009)

Table 3 (continued)

Plant's species	Plant's parts	Phytochemicals	Antimicrobial properties	References
Tamarindus indica	Fruit, leaf, seed	Apigenin, lupeol, catechin, epicatechin, procyanidin dimer, procyanidin trimer, taxifolin, eriodictin, naringenin	*Burkholderia pseudomallei*, *Staphylococcus aureus*, *Klebsiella pneumonia*, *Bacillus subtilis*, *Salmonella paratyphi*, *Salmonella* Typhi	Bhadoriya et al. (2011)
Aegle marmelos	Leaf, bark, fruit	Aegeline, aegelenine, marmelin, aegelinosides, malondialdehyde, marmelosin, anhydromarmeline, marmelide	*Klebsiella pneumoniae*, *Proteus mirabilis*, *Salmonella paratyphi A* and *B, Escherichia coli*, *Staphylococcus aureus*, *Bacillus subtilis*	Mujeeb et al. (2014)
Woodfordia fruticosa	Leaf, flower	B-caryophyllene, β-selinene, α-pinene, germacrene-D, elemol, γ-curcumene, 2,6-dimethyl-1,3,5,7-octatetraene	*Pseudomonas aeruginosa*, *Escherichia coli*, *Staphylococcus aureus*, *Bacillus subtilis*, *Micrococcus flavus*, *Salmonella* Typhi, *Citrobacter freundii*, *Salmonella paratyphi*	Kaur and Kaur (2010)
Mangifera indica	Stem, seed, fruit, leaf	1,2-benzenedicarboxylic acid, 2-ethylhexyl ester, 9,12-tetradecadiene,1-ol, acetate, 3-chloro-N-propanamide	*Bacillus pumilus*, *Bacillus cereus*, *Staphylococcus aureus*, *Escherichia coli*, *Salmonella agon*, *Klebsiella pneumoniae*, *Salmonella cerevisiae*, *Trichoderma reesei*	Shah et al. (2010)
Abutilon indicum	Root, bark, flower, leaf, seed	DPPH, potassium ferricyanide, trichloro acetic acid, ascorbic acid, phosphoric acid, BHA, nitro blue tetrazolium, phenazine methosulfate	*Staphylococcus aureus*, *Bacillus subtilis*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Candida albicans*	Kaushik et al. (2010
Bombax ceiba	Stem, flower, root, seed, fruit, leaf	C-glucoside, β-D-glucoside, free β-sitosterol, lupeol, hentriacontane, shamimin, hentriacontanol, hemigossipol, kaempferol, quercetin	*Klebsiella pneumoniae*, *Bacillus subtilis*, *Bacillus aureus*, *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Salmonella* Typhimurium	Chaudhary and Khadabadi (2012)
Bacopa monnieri	Leaf, stem, flower, root	Tetracyclic triterpenoids saponins, bacosides A and B, phytosterols, hersaponin, luteolin-7-glucoside, glucoronyl-7-apigenin	*B. subtilis*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, *Microsporum audouinii*, *Candida albicans*, *Trichophyton mentagrophytes*, *Aspergillus niger*, *Salmonella* Typhimurium	Alam et al. (2011)

(including leaf, seed, root, and stem) reported that the seed extract of *Amaranthus hybridus* in hexane exerted the higher antibacterial potential of 93.7% by against *S. enterica* serovar *typhi* at 1.25 mg/mL concentration. Moreover, the leaf extract of *Aloe barbadensis* and chloroform leaf extract of *Adhatoda vasica* exhibited 92.3% and 80.5% anti-salmonella potential at 10 mg/mL and 40 mg/mL concentration, respectively (Naz et al. 2022).

More recently, ethanolic extracts of 24 plants from Benin folk medicine system were screened for their in vitro and in vivo anti-salmonella activity against clinical resistant strain of *Salmonella enterica* serovar typhimurium. Out of 24 plants, 18 plant extracts were reported to exhibit the promising anti-salmonella potential with maximum activity observed in *Anacardium occidentale*, *Artemisia afra*, *Detarium microcarpum*, *Detarium senegalense*, and *Leucaena leucocephala* against *Salmonella enterica* strains with minimum inhibitory concentrations (MICs) ranging from 0.156 to 1.25 mg/mL (Amoussa et al. 2023). A much recent study documenting the potential of ethanolic extracts of *Hibiscus sabdariffa* and *Aspilia africana* was found to exhibit both bactericidal and bacteriostatic activities against resistant *S.* Typhi and sensitive *S.* Typhi with MIC value of 3.125–6.125 mg/mL and 12.5–25 mg/mL, respectively. Further, a synergistic study of ethanol extracts of *H. sabdariffa*, *A. africana*, and ciprofloxacin indicated effective MBC value of 0.19–0.39 mg/mL to 0.097–0.19 mg/mL against both the sensitive and resistant strains of *S.* Typhi, respectively (Balali et al. 2023). Apart from exploring the various solvent extracts of medicinal plants for anti-salmonella potential, multiple compounds have been purified from medicinal plants inhabiting diverse habitats with remarkable activity against *Salmonella* species (Table 4 and Fig. 1).

Herbal formulations from clinical trials to commercialization against *Salmonella* sp.

Numerous medicinal plants with broad spectrum antimicrobial potential have gained importance in recent years to be developed as herbal medicines as an alternative to conventional antibiotics for catering the infections caused by multi-drug resistant microbes (Khameneh et al. 2021). The herbal medicines/formulations are usually mixture of two or more complex bioactive constituents derived from various ethnobotanical plants while ensuring dosage, efficacy, and safety. Few of such herbal formulations native to certain regions across the globe are well adopted by local people for combating the infections caused by *Salmonella* species.

Table 4 Anti-salmonella potential of purified compound from medicinal plants, Mechanism of action and MIC value

Name of compound	Plant's species	Target organism	Mechanism of action	MIC/IC_{50}	References
Baicalein	*Scutellaria baicalensis*	*Salmonella* typhimurium	Inhibition of efflux pump	MIC = 64 µg/mL	Wu et al. (2018)
Aegelinol	*Ferulago campestris*	*Staphylococcus aureus*, *Salmonella* typhi, *Enterobacter cloacae*, and *E. aerogenes*	Cell membrane disruption act as DNA Gyrase inhibitor	MIC = 16 µg/mL	Basile et al. (2009); Razavi et al. (2013)
Agasyllin	*Ferulago campestris*	*Staphylococcus aureus*, *Salmonella* typhi, *Enterobacter cloacae*, and *E. aerogenes*	Cell membrane disruption act as DNA Gyrase inhibitor	MIC = 32 µg/mL	Basile et al. (2009)
4′-Senecioiloxyosthol	*Prangos hulusii*	*S. enterica* serovar typhi	DNA Gyrase inhibitor	-	Tan et al. (2017)
Stemmoside C	*Solenostemma argel*	*S. enterica* serovar typhi	Anti-inflammatory cytokine production	16 µg/mL	Plaza et al. (2004); El-Sheikh and Elshimy (2023)
Resveratrol	*Vitis vinifera*	*Salmonella* typhimurium	Membrane and DNA disruption via pro-oxidant activity	5 µg/mL	Jeandet et al. (2002); Paulo et al. (2010); Lee and Lee (2017)
Punicalagin	*Punica granatum* L	*Salmonella* typhimurium	Membrane disruption	0.25 to 1 mg/mL	Li et al. (2015, 2020)
Lariciresinol	*Zingiber officinale*	*Salmonella* typhimurium	Efflux pump inhibitor		Mehta et al. (2022)
Scopoletin	*Canarium schweinfurthii*	*Salmonella* typhimurium *and Salmonella enteritidis*	-	MIC = 16 µg/mL	Sokoudjou et al. (2020)

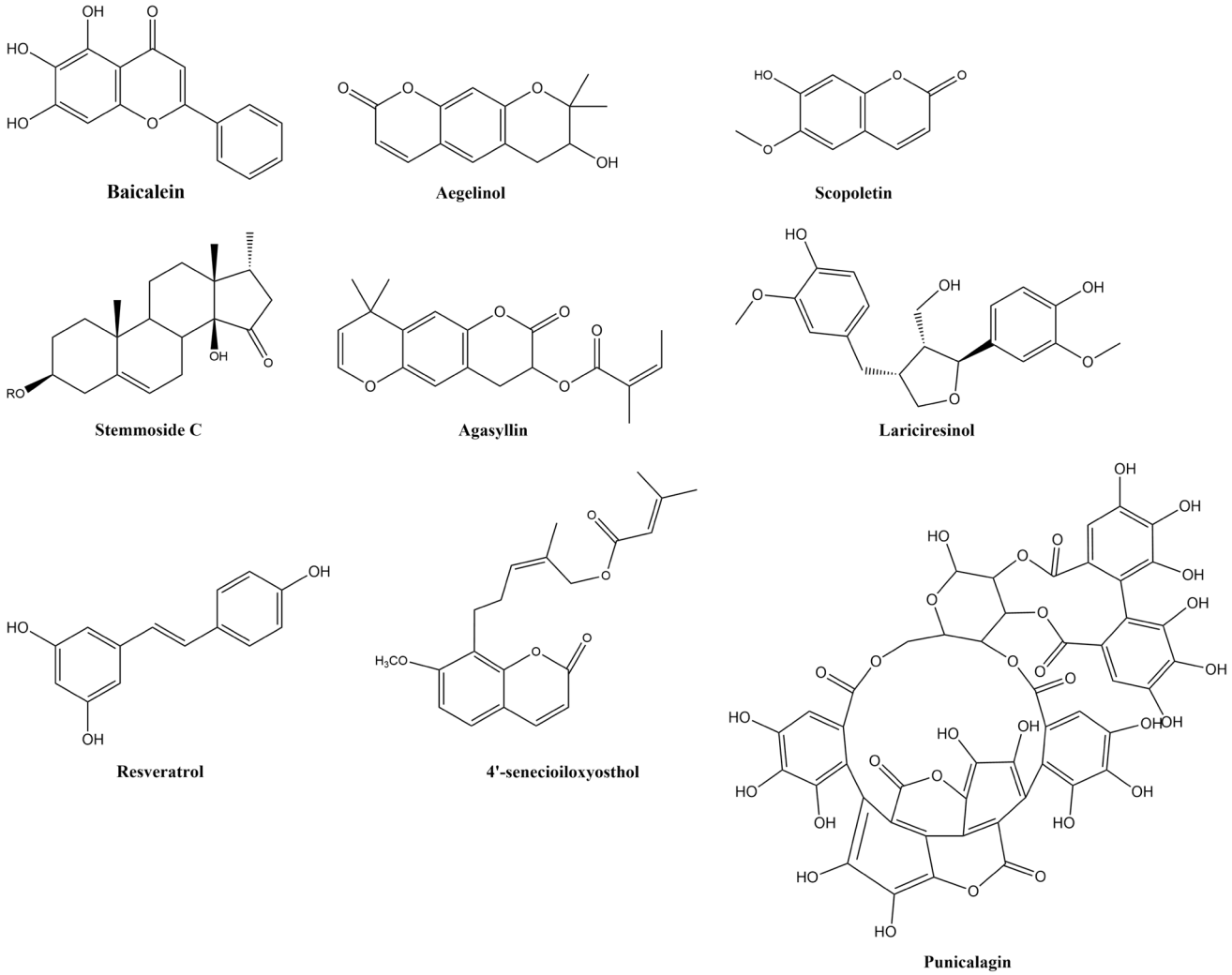

Fig. 1 Structures of major plant-derived compounds for potent anti-salmonella activity

MA 001

Since last two decades, an aqueous herbal decoction, namely, MA 001, manufactured by the Centre for Plant Medicine Research (CPMR), Mampong-Akuapem, has been deployed for the treatment of typhoid fever among local communities in Ghana. It is registered with the Food and Drugs Authority of Ghana under the brand name MA 001 (FDA/HD.07–7097). MA 001 is formulated from various plant parts, viz., leaves and aerial parts of *Citrus aurantifolia*, *Spondias mombin*, *Lantana camara*, *Bidens pilosa*, *Trema occidentalis*, *Psidium guajava*, *Morinda lucida*, *Vernonia amygdalina*, *Persea americana*, *Paullinia pinnata*, *Momordica charantia*, and *Cnestis ferruginea*. With a pre-requite to improve the stability, taste, and palatability along with strict compliance, the MA 001 formulation has also been developed in the form of capsules as well as effervescent granules (Kumadoh et al. 2015; Adi-Dako et al. 2021). For the treatment of typhoid fever, dosage regimen of 30 mL of MA 001 three times daily for 3 weeks was fixed. The batch-to-batch consistency analysis of MA 001 formulation based upon organoleptic, physicochemical parameters, pharmacological, and safety was found to pass all the quality standards thereby ensuring reproducibility, efficacy, and safety of MA 001 decoction (Adi-Dako et al. 2023).

Scutellaria baicalensis Georgi (SBG)

It is considered to be golden medicinal herb in Japanese and Chinese pharmacopeia due to the presence of active compound baicalein (Zhao et al. 2016). Traditionally, SBG is being deployed for the treatment of inflammatory and range of infectious disorders including pathopyretic sores, ulcers, or pustules (Xing et al. 2017). The SBG was found to exert antibacterial action towards a wide range of pathogenic

bacteria such as *Staphylococcus aureus*, *S. mutans*, *E. coli*, *P. aeruginosa*, *Salmonella enterica*, *S. epidermidis*, and *Propionibacterium acnes* (Zhao et al. 2019). Multiple studies demonstrated the effect of SBG alone or in combination with potent antibiotics to control the infectious diseases by blocking CTX-M-1 mRNA expression (Cai et al. 2016), increasing cytoplasmic membrane permeability (Siriwong et al. 2015), and inhibiting the NorA efflux pump activity and pyruvate kinase enzyme (Chan et al. 2011).

Houttuynia cordata Thunb (HCT)

In the Chinese pharmacopeia, fresh/dried aerial portion of *Houttuynia cordata* Thunb. (HC) is being administered to treat various diseased conditions such as purulent, suppuration, sores, pustules, and respiratory infections (Hemalatha et al. 2014). The main active constituent Houttuynia exerts potent antibacterial effect against range of pathogenic organisms by adopting different mechanisms such as inhibition of interleukin-8 (IL-8) and C–C motif chemokine ligand 20 (Sekita et al. 2016). The water extract of HCT could effectively treat intracellular bacterial infections caused by *Salmonella* in the RAW macrophage cell line. The stability and efficacy of HCT water extract were ascertained by analyzing virulence reduction activities in *Salmonella* Typhimurium–infected BALB/c mice (Kim et al. 2008).

Gegen Qinlian (GQ) oral liquid

GQ decoction, a classic TCM formulation, is composed of four herbs, namely, *Puerariae Radix*, *Scutellaria baicalensis* Georgi, *Coptis chinensis* Franch, and *Glycyrrhizae Radix et Rhizoma Praeparata cum Melle*, and was observed to inhibit *Salmonella*, *Enterococcus*, and *E.coli* with MIC value of 41.7 µg/mL, 20. 83 µg/mL, and 62.5 µg/mL, respectively (Liang et al. 2022).

Shorea robusta Gaertn (SRG)

In Indian traditional medicine, *Shorea robusta* L. is used for ameliorating diverse ailments. Traditionally, the chief bioactive constituent, the gum resin, is used to control diarrhea, dysentery, gonorrhea, and as astringent. A survey-based study conducted over the tribals of Birhore, Jharkhand region in India, revealed that local communities were consuming 7–10 tender leaves of *S. robusta* along with black pepper (*Piper nigrum* L.) for 7 days two times in a day to control long-term fever. Chattopadhyay et al. (2018) investigated the scientific reasons of anti-salmonella potential of methanolic and aqueous leaf extracts of *S. robusta* against 40 multi-drug-resistant (MDR) clinical isolates of *S.* Typhi, and it was found to have promising results with MIC and MBC of the extracts observed to be 256–450 µg/mL against *S.* Typhi isolates, while MBC was ≤ 512–1024 µg/mL.

Conclusion

Globally, the mounting incidence and prevalence rate of *S. enterica* infections coupled with the rapid emergence of MDR strains are posing a daunting challenge that necessitates the exploration of alternative and innovative strategies. Due to the exponential upsurge in the number of resistant strains against conventional antibiotics, major emphasis is being laid on discovery of novel antibiotics to cater for the severity. In the aspect of the antibiotic resistance crisis, phytochemicals derived from medicinal plants arise as valuable allies in the continuing battle against *Salmonella enterica*. The present review underpins and exemplifies the substantial contribution of phytochemicals, harbored from medicinal plants inhabiting diverse geographical regions and climatic conditions, in the fight against *S. enterica* infection. Several studies demonstrating the anti-salmonella potential of plant extracts and purified compounds with rich structural and functional attributes offer a promising avenue for developing phytodrugs as an alternative to combat *S. enterica* infection. Moreover, the drastic transition from traditional medicine to evidence-based herbal formulations marks a promising trend. Further studies shall be directed at tapping the novel medicinal chemistries as herbal formulations against antibiotics against drug-resistant pathogens. The development of these formulations, from clinical trials to commercialization, embodies a step towards integrating traditional wisdom with modern healthcare practices. The development of plant-derived drugs not only adheres to the principles of sustainable development but also provides solutions for sapping the challenges posed by drug-resistant strains. Further, the herbal formulations have been highlighted as adjuvants making the drug-resistant bacteria sensitive to the antibiotics. Thus, antibiotic-herbal adjuvant combinatorial therapy has the potential to be used as an effective therapy to overcome antibiotic resistance by bacteria. With persisting advancement in the field of phytodrugs, the development of innovative and persuasive phytochemical-based therapies can pave the way to crucial breakthroughs in extenuating the worldwide repercussions of *Salmonella* infections.

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Declarations

Conflict of interest The authors declare no competing interests.

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