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Plants from the Lamiaceae, Asteraceae, and Malvaceae families used in traditional mexican medicine with antibacterial properties

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Abstract

In Mexico, medicinal plants have been integral to pre-Hispanic cultures since ancient times. Studies of the Lamiaceae, Asteraceae, and Malvaceae families have identified species with antibacterial properties, which represents a promising alternative for combating resistant bacteria that cause human disease and a source of new chemical compounds helpful in repairing the damage caused by these microorganisms. This review focuses on studies of the antibacterial activity of plants from the aforementioned families used in traditional Mexican medicine against gram-positive (+) and gram-negative (-) bacteria. It also provides a brief botanical description of some of these plants, including their uses, structural components, and types of extracts with bactericidal activity, inhibited bacterial strains, zone of inhibition, and minimum inhibitory concentration (MIC). Finally, a description of the identified compounds with antibacterial potential and their possible mechanisms of action is provided.
Keywords: medicinal plants, antibacterial activity, Lamiaceae, Malvaceae, and Asteraceae.

Plantas de las familias Lamiaceae, Asteraceae y Malvaceae, utilizadas en la medicina tradicional mexicana con propiedades antibacterianas

Resumen

En México, desde tiempos antiguos, las plantas medicinales han sido parte integral de las culturas prehispánicas. En estudios realizados a las familias Lamiaceae, Asteraceae y Malvaceae han encontrado especies con propiedades antibacterianas, lo que representa una alternativa prometedora para combatir a las bacterias resistentes que son causa de enfermedades en los humanos, y una fuente de nuevos compuestos químicos útiles para resarcir el daño que ocasionan estos microorganismos. La presente revisión se centra en estudios de la actividad antibacteriana, contra bacterias grampositivas (+) y gramnegativas (-), de plantas de las familias antes citadas y utilizadas en la medicina tradicional mexicana. También se aborda una breve descripción botánica de algunas de ellas, su uso, las partes de su estructura y los tipos de extractos con actividad bactericida, las cepas bacterianas inhibidas, la zona de inhibición y la concentración mínima inhibitoria (CMI). Finalmente, una descripción de los compuestos identificados con potencial antibacteriano y su posible mecanismo de acción.
Palabras clave: plantas medicinales, actividad antibacteriana, Lamiaceae, Malvaceae y Asteraceae.

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Introduction

Medicinal plants have been a fundamental pillar in the traditional medicine of diverse cultures worldwide. Mexico, with its rich biodiversity and cultural heritage, is no exception. Mexico is recognized for containing many plants with medicinal properties, many of which have significant antimicrobial activity (Mata, Figueroa, Navarrete & Rivero-Cruz, 2019). Due to its geographical and climatic diversity, Mexico contains approximately 4,500 identified species of medicinal plants (Cruz-Pérez, Barrera-Ramos, Bernal-Ramírez, Bravo-Avilez & Rendón-Aguilar, 2021). The use of these plants dates back to pre-Hispanic cultures such as the Aztecs, Mayans, Otomi, and Mixtecs and continues to be relevant in traditional Mexican medicine (Cabada-Aguirre, López, Mendoza, Garay, Luna-Vidal & Mahady, 2023).

In Mexico, plants of the Lamiaceae, Malvaceae, and Asteraceae families contain many medicinal plants, some known for their antibacterial properties (Sharma, Flores-Vallejo, Cardozo-Taketa & Villareal, 2017). In the Lamiaceae family, we can find peppermint (*Mentha* x *piperita*), oregano (*Origanum vulgare*), basil (*Ocimum basilicum)*, and rosemary (*Rosmarinus officinalis*), (Martínez-Gordillo *et al.*, 2017). Malvaceae include cocoa (*Theobroma cacao*), roselle (*Hibiscus sabdariffa*), and cotton (*Gossypium hirsutum*), among others (Robles-Valdivia & Sánchez-Otero, 2022). Finally, in the Asteraceae, we find Mexican arnica (*Heterotheca inuloides* Cass.), calendula (*Calendula officinalis* L.), and marigold (*Tagetes erecta* L.) (Ortiz-Bermudez, Villaseñor & Tellez, 1998).

The antibacterial properties of these plants are due to active compounds found in essential oils and organic extracts. The active compounds act at the level of the cell wall and membrane; this generates a destabilization of the bacterial structure, denaturing and coagulating proteins, altering the permeability of the cytoplasmic membrane, causing the loss of nutrients, and leading to the deterioration of essential cell processes such as electron transport, protein translocation, and oxidative phosphorylation, among others. This results in the loss of osmotic control of the bacterial cell, causing cell death (da Silva Ramos *et al.*, 2017; Marjanović-Balaban *et al*., 2018). For example, the essential oil of peppermint contains active compounds such as menthol and menthone, responsible for its antibacterial activity against different gram-positive (+), (*Staphylococcus aureus* and *Listeria monocytogenes*) and gram-negative (-) bacterial strains (*Salmonella enterica*, *Escherichia coli*, and *Pseudomonas aeruginosa*), (Figure 1, Table I), (Marjanović-Balaban *et al*., 2018). Similarly, rosemary's antimicrobial properties are attributed to the presence of specific terpenes in its essential oil, such as α-pinene, 1,8 cineole, linalool, camphor, *β*-caryophyllene, and α-caryophyllene (Elyemni, El Ouadrhiri, Lahkimi, Elkamli, Bouia & Eloutassi, 2022). Another important plant is Mexican arnica, commonly used as an anti-inflammatory and relieving pain. Analysis of the hexanoic extract of arnica flowers revealed the presence of sesquiterpenoids such as 7-hydroxy-3,4-dihydrocadalin, 7-hydroxycadalin, β-caryophyllene, and β-caryophyllene-4,5α-oxide. These compounds demonstrated antimicrobial properties against gram-positive bacteria *Bacillus subtillis*, *Streptococcus mutans*, *S. aureus*, *Brevibacterium ammoniagenes*, and *Propionibacterium acnes* (Figure 1, Table II), (Kubo, Muroi, Kubo, Chaudhuri, Sanchez & Ogura, 1994). Additionally, the bactericidal activity of cocoa bark extract is attributed to the presence of alkaloids. Alkaloids create an alkaline environment, leading to protein coagulation and altering cell wall components such as peptidoglycan (Ramadhanie, Purwaningsih & Koendhori, 2020).

With the rising issue of antibiotic resistance, studying medicinal plants with antibacterial activity is crucial. These plants offer potential sources of new antibacterial compounds effective against resistant microorganisms. Diseases caused by gram-positive (+) and gram-negative bacteria (-) are the leading cause of mortality worldwide (O'neil, 2014). The World Health Organization (WHO) indicates that by 2050, there will be 10 million deaths associated with bacterial diseases (O'neil, 2014). For example, the bacteria *S. aureus* (+) is a pathogen with a high potential to cause various human infections. *S. aureus* is considered one of the most virulent bacteria, associated with many human diseases, from skin infections to severe, life-threatening illnesses such as infectious arthritis, pneumonia, and osteomyelitis. A concerning aspect is the resistance of certain strains of *S. aureus* to various antibiotics, such as methicillin (Ghalehnoo, 2018; O'neil, 2014). Interestingly, extracts of peppermint, Mexican arnica, oregano, basil, rosemary, marigold, calendula, cocoa, and roselle can inhibit the growth of *S. aureus* (Tables I, II and III), (Elyemni *et al.*, 2022; Kubo *et al.*, 1994; Marjanović-Balaban *et al.*, 2018; Oniga *et al.*, 2018; Padalia & Chanda, 2015; Stanojevic, Marjanovic-Balaban, Kalaba, Stanojevic, Cvetkovic & Cakic, 2017). Most of these plants are grown in the backyards of Mexican families because they are used in traditional Mexican cuisine and to prepare home remedies for various human ailments (Sharma *et al.*, 2017).

This review discusses recent studies of plants used in traditional Mexican medicine with antibacterial activity against gram-positive (+) and gram-negative bacteria (-). The selected plants are from the Lamiaceae, Asteraceae, and Malvaceae families. The members of the families considered in this review are popularly used in Mexican medicine. It includes a brief botanical description of the plants, their use in traditional medicine, the parts of the plant and the type of extract used for antibacterial activity, the bacterial strains inhibited, the zone of inhibition, and the MIC values of the plant extract. Finally, the active compounds with potential antibacterial activity and their possible mechanism of action are described. This review aims to provide updated and relevant information to assist in the assertive selection of plants used in Traditional Mexican

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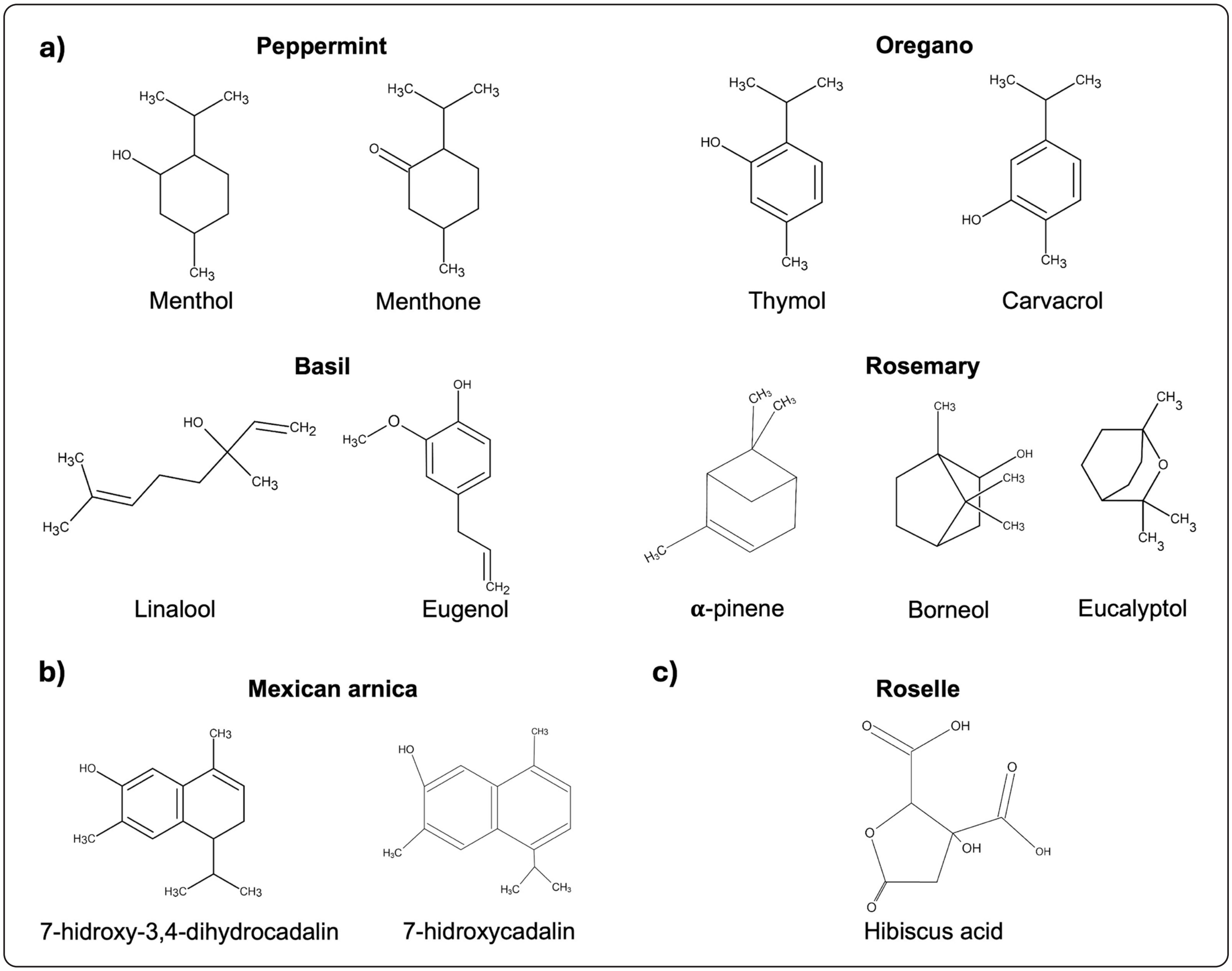

Figure 1. Chemical structures of the primary compounds with reported antibacterial properties from plants in the a) Lamiaceae, b) Asteraceae, and c) Malvaceae families. The chemical structure of the compounds was consulted from Allenspach & Steuer (2021); Eisenbrand *et al.* (2021); Izquierdo-Vega *et al.* (2020); Kubo *et al.* (1994); Loolaie, Moasefi, Rasouli & Adibi (2017); Mediouni *et al.* (2020); Suppakul, Miltz, Sonneveld & Bigger (2003).

Medicine with more significant *in vitro* potential regarding their antibacterial properties. It also aims to provide valuable information for developing studies focused on finding new candidate drugs with antibacterial properties and those aimed at combating specific pathogenic bacteria.

Methods

The information was collected systematically following the PRISMA model (Preferred Reporting Items for Systematic Review and Meta-Analyses). Five stages previously used in systematic reviews were followed: **I)** formulation of questions, **II)** determination of the search strategy, **III)** selection of articles, **IV)** analysis processes, and **V)** analysis of results (Page *et al.*, 2021; Zambrano & Sánchez, 2022).

We raised the following research questions: What are the Lamiaceae, Asteraceae, and Malvaceae family species that present antimicrobial properties? What bioactive compounds have been identified in plants, and what are their mechanisms of action? What bacterial strains are more susceptible to the extracts of these plants? What is the relevance of plants in traditional Mexican medicine and their potential alternative to conventional antibiotics? We carried out a literature search in recognized academic databases, such as PubMed, Scopus, Google Scholar, and Web of Science, selected due to their wide coverage of publications in medicine, pharmacology, and ethnobotany. We performed a search by a time-based scan using specific keywords such as “Lamiaceae”, “Asteraceae”, “Malvaceae”, “traditional Mexican medicine” and “antibacterial activity”.

Table I. Antibacterial activity of plants from the Lamiaceae family against gram-positive and gram-negative bacteria. MIC, Minimum inhibitory concentration; Nd, not detected; (+), gram-positive bacteria; and (-), gram-negative bacteria.

Common name/ Species	Chemical group	Main compounds	Plant tissue	Extract	Tested bacteria	MIC	Volume/ Concentration	Inhibition zone	References
Peppermint/ *M. piperita*	Oxygenated and hydrocarbon monoterpenes, and oxygenated and hydrocarbon sesquiterpenes	Menthol, menthone, iso-menthone, 1,8-cineole, and methyl acetate	Leaves	Essential oil	*P. aeruginosa* (-) *L. monocytogenes* (+) *E. coli* (-) *S. enterica* (-) *S. aureus* (+)	Nd	20 µL	32.33 mm 21.00 mm 27.33 mm 27.33 mm 37.77 mm	(Marjanović-Balaban *et al.*, 2018)
	Terpenoids, and monoterpenes	Menthol, L-menthone, limonene, methyl acetate, carveone, neomenthol, and cineole	Aerial part	Essential oil	*B. cereus* (+) *S. mutans* (+) *K. pneumoniae* (-) *S. flexneri* (-) *S. dysenteria* (-)	0.25 µL/mL 0.25 µL/mL 0.25 µL/mL 0.5 µL/mL 0.5 µL/mL	16 to 0.25 µL/ mL	Nd	(Mahboubi & Kazempour, 2014)
	Oxygenated and hydrocarbon Monoterpenes, and hydrocarbon sesquiterpenes	Linalool, thuja-2,4(10)-diene, β-pinene , mentha-2,8-diene β-ocimene, epizonarene, epoxyocimene, sesquiphellandrene, cadinene, and germacrene	Leaves	Essential oil	*S. aureus* (+) *E. coli* (-)	Nd	100 mg/mL 100,50, 10, 1.0 mg/mL	7.6 mm 7.6, 7.0, 9.0, 7.3 mm	(da Silva Ramos *et al.*, 2017)
	Nd	Nd	Leaves	Essential oil	*S. aureus* (+) *S. pyogenes* (+) *E. coli* (-) *K. pneumonia* (-)	0.5 % 0.5 % 0.7 % 0.4 %	10 µL	17.2 mm 13.1 mm 5.1 mm 12. 4 mm	(Singh *et al.*, 2015)
Oregano/ *O. vulgare*	Phenolic compounds, and flavonoids	Gentisic acid, chlorogenic acid, p-coumaric, rosmarinic acid; hyperoside, isoquercitrin, rutin, quercitrin, quercetin, and luteolin	Aerial part	Ethanol	*L. monocytogenes* (+) *S. aureus* (+) *S. enteritidis* (-) *E. coli* (-)	156.25 µg/ mL 78.13 µg/mL 78.13 µg/mL 156.25 µg/ mL	60 µL	17 mm 16 mm 18 mm 16 mm	(Oniga *et al.*, 2018)
	Nd	Nd	Leaves	Ethanol	*S. aureus* (+) *P. aeruginosa* (-) *E. coli* (-)	Nd	80, 40, 20 mg/ mL	21.64, 15.24, 11.45 mm 13.31, 12.27, 7.35 mm 12.5, 11.4 10.6 mm	(Pérez-Delgado *et al.*, 2021)

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Table I. Antibacterial activity of plants from the Lamiaceae family against gram-positive and gram-negative bacteria. MIC, Minimum inhibitory concentration; Nd, not detected; (+), gram-positive bacteria; and (-), gram-negative bacteria (*continuation*).

Common name/ Species	Chemical group	Main compounds	Plant tissue	Extract	Tested bacteria	MIC	Volume/ Concentration	Inhibition zone	References
Basil/*O. basilicum*	Oxygenated monoterpenes, and oxygenated and hydrocarbon sesquiterpenes	Thymol, carvacrol, linalool, terpineol, eugenol, and methyl chavicol	Seeds	Essential oil	*S. aureus* (+) *B. cereus* (+) *L. monocytogenes* (+) *Streptococcus* group D (+) *P. aeruginosa* (-) *E. coli* (-) *S. enterica* (-) Coagulase-positive *Staphylococcus*	Nd	20 µL	15.66 mm 9.66 mm 14 mm 30 mm 13.33 mm 29.33 mm 28.33 mm 40 mm	(Stanojevic *et al.*, 2017)
	Nd	Nd	Aerial part	Essential oil	*S. aureus* (+) *B. cereus* (+) *E. coli* (-) *P. aeruginosa* (-)	18 µg/mL 18 to 36 µg/mL 9 to 18 µg/mL 9 to 18 µg/mL	20 µL	29.20 to 30.56 mm 10.66-16.11 mm 17.24 to 23.58 mm	(Moghaddam *et al.*, 2011)
Rosemary/ *R. officinalis* L.	Oxygenated sesquiterpenes, and hydrocarbon monoterpenes	α-pinene, 1,8-cineole, linalool, borneol, camphor, β-caryophyllene, and α-caryophyllene	Aerial part	Essential oil	*S. aureus* (+) *B. subtilis* (+) *E. coli* (-) *P. aeruginosa* (-)	0.625 mg/mL 0.315 to 1.25 mg/L 1.25 to 5 mg/L 2.5 to 5 mg/L	Nd	Nd	(Elyemni *et al.,* 2022)
	Terpenoids, and monoterpenes	1,8 cineole, α-pinene, caphor, borneol, and verbenone	Complete plant	Essential oil	*S. aureus* (+) *E. coli* (-)	0.625 % 1.25 %	100 µL	Nd	(Jafari-Sales & Pashazadeh, 2020)

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Table II. Antibacterial activity of plants from the Asteraceae family against gram-positive and gram-negative bacteria. MIC, Minimum inhibitory concentration; Nd, not detected; (+), gram-positive bacteria; and (-), gram-negative bacteria.

Common name/Species	Chemical group	Main compounds	Plant tissue	Extract	Tested bacteria	MIC	Volume/ Concentration	Inhibition zone	References
Marigol/ *T. erecta* L.	Nd	Nd	Leaves	Aqueous	*P. acnes* (+) *S. pneumoniae* (+) *B. cereus* (+) *A. baumannii* (-) *E. coli (-)*	Nd	100 µL	0.90 mm 0.02 mm 0.77 mm 0.91 mm 0.81 mm	(Dasgupta *et al.*, 2012)
	Nd	Nd	Petals	Ethanol	*S. agalactiae* (+)	Nd	25, 50, 75 mg/ mL	7.33, 8.33, 8.83 mm	(Mekvimol *et al.*, 2020).
	Flavonoids, tannins, triterpenes, and cardiac glycoside	Nd	Flowers	Acetone	*B. cereus* (+) *B. subtilis* (+) *S. aureus* (+) *S. albus L.* (+) *L. monocytogenes* (+) *P. pseudoalcalifenes* (-) *P. morganii* (-) *P. aeruginosa* (-) *K. pneumoniae* (-)	78 µg/mL 1250 µg/mL 625 µg/mL 312 µg/mL 156 µg/mL 312 µg/mL 1250 µg/mL 62µg/mL 78 µg/mL	Nd-	Nd	(Padalia & Chanda, 2015)
Mexican arnica/ *H. inuloides* Cass.	Sesquiterpenes	7-hydroxy-3,4-dihydrocadalin, and 7-hydroxycadalin	Flowers	Hexane	*S. aureus* (+) *B. subtilis* (+) *B. ammoniagenes* (+) *S. mutans* (+)	6.25-12.5 µg/mL	Nd	Nd	(Kubo *et al.*, 1994)
	Sesquiterpenes	7-hydroxycadalene, caryophyllene, and δ-cadinene	Complete plans	Supercritical carbon dioxide	*S. aureus* (+) *P. aeruginosas* (-) *E. coli* (-)	Nd	Nd	1 cm 0.2 cm 0.8 cm	(García-Pérez *et al.*, 2016)
Calendula/ *C. officinalis* L.	Terpenoids, and monoterpene	1,8-cineole, β-caryophyllene, carvacrol, terpinolene, and camphene	Flowers	Essential oil	*S. aureus* (+) *B. cereus* (+) *E. coli* (-) *P. aeruginosa* (-) *S. typhi* (-)	Nd	0.5 mg/mL	3.14 mm 4.10 mm 13.31 mm 10.22 mm 7.34 mm	(Chaleshtori *et al.*, 2016)
	Nd	Nd	Flowers	Essential oil	*S. aureus* (+) *E. coli* (-) *P. aeruginosa* (-)	Nd	2.5 µL	3.14 mm 13.31 mm 10. 22 mm	(Arora *et al.*, 2013)
	Nd	Nd	Leaves	Ethanol, and chloroform	*S. aureus* (+) *B. cereus* (+) *B. subtilis* (+) *E. faecalis* (+) *S. typhimurium* (-) *P. vulgaris* (-) *E. cloacae* (-) *K. rhizophila* (-)	Nd	60 µL	26 to 38 mm 28 to 32 mm 20 to 24 mm 18 to 20 mm 10 to 14 mm 12 to 18 mm 10 mm 13 to 16 mm	(Çetin *et al.*, 2017)

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Table III. Antibacterial activity of plants from the Malvaceae family against gram-positive and gram-negative bacteria. MIC, Minimum inhibitory concentration; Nd, not detected; (+), gram-positive bacteria; and (-), gram-negative bacteria.

Common name/Species	Chemical group	Main compounds	Plant tissue	Extract	Tested bacteria	MIC	Volume/ Concentration	Inhibition zone	References
Roselle/ *H. sabdariffa*	Organic acid	Hibiscus acid	Flowers	Acetone	*Salmonella C1* (-) *Salmonella C65* (-) *Salmonella C63* (-) *E. coli C558* (-) *E. coli C636* (-)	4 to 7 mg/ mL	20 µL	12.6 to 16 mm 10.8 to 14.5 mm 10.3 to 11.5 mm 11,6 to 11.8 mm 10.4 to 11.1 mm	(Portillo-Torres *et al.*, 2019)
	Nd	Nd	Flowers	Aqueous	*S. aureus* (+) *S. faecalis* (+) *E. coli* (-) *K. pneumoniae* (-)	0.5 mg/mL 0.5 mg/mL 1.0 mg/mL 1.0 mg/mL	Nd	Nd	(Navarro García *et al.,* 2006)
	Alkaloids, phenols, tannins, and coumarins	Nd	Leaves	Ethanol	*Salmonella typhi* (-)	6,25 and 3,125 mg/ mL	Nd	Nd	(Balali *et al.,* 2023)
Cocoa/ *T. cacao*	Polyphenols, tocopherols, and flavonoids	Nd	Complete plants	Aqueous	*S. aureus* (+) *S.mutans* (+) *S. typhi* (-) *E. coli (-)* *S. dysenteriae* (-) *E. faecalis* (+)	Nd	30%	37 mm 36 mm 33 mm 31 mm 30 mm 33 mm	(Al-Shalah *et al.*, 2022)
	Alkaloids, tannins, saponins, glycosides, phenol, and carboxylic acids	Nd	Stem	Chloroform	*S. aureus* (+) *S. pneumoniae* (+) *P. aeruginosa* (-) *E. coli* (-)	Nd	Nd	21 to 30 mm 28 to 30 mm 25 to 30 mm 27 to 31 mm	(Olaleye & Ogunbiyi, 2022)
Cotton/ *G. hirsutum* L.	Fatty acid	9,12,15-octadeca-trienoic acid, n-hexadecanoic acid, 9,12-octadeca-dienoic acid (Z,Z)-linoleic acid, hexadecanoic acid, palmitic acid methyl ester, and linoleic acid methyl ester	Seeds	Ethanol	*S. aureus* (+) *E. coli* (-)	Nd	50 µg/mL 100 µg/mL	20 mm 13 to 20 mm	(Krishnaveni *et al.*, 2014)
	Nd	Nd	Leaves	Hexane	*S. aureus* (+) *S. pneumoniae* (+) *E. faecalis* (+) *E. coli* (-)	2.5 mg/mL 1.2 mg/mL >5 mg/mL >5 mg/mL	Nd	Nd	(Rojas *et al.*, 2001)
	Phenols	Gossypol, heliocides, and hemigossipolone	Leaves, inflorescence, and stem	Ethanol	*S. aureus (+)*		200 mg/mL 500 mg/mL	8 mm 10 mm	(Miranda *et al.*, 2013)

Then, through the Boolean operators "AND" and "OR," the results were limited by the combination [(Lamiaceae"), ("Asteraceae"), ("Malvaceae")] "AND" [("traditional Mexican medicine ") "OR" ("antibacterial activity")].

The inclusion criteria focused on original studies published in English or Spanish that address the antibacterial activity of the mentioned family of plants and their use in traditional Mexican medicine. The research was considered between 2000 and 2024, including research articles, reviews, books, and book chapters, all published on official pages and that has gone through a peer review process. Only works before that date were considered due to their relevance and contribution to the objective of the work. The initial search yielded 150 documents, and after evaluating the titles, abstracts, and results of the works, we selected only 78 papers due to their relevance and contribution to the objective of the work. We considered during the analysis of results and data collection of the selected studies, the following: year of publication, plant species, plant tissue used, type of extract, method of evaluation of antimicrobial activity, bacterial strains tested, minimum inhibitory concentration (MIC), diameter of the inhibition zone. We excluded articles not related to antibacterial activity, unrelated reports or studies, and those outside the established period that did not provide relevant information associated with the objective of the work. Finally, we critically analyzed the selected data to offer an updated and detailed perspective of each topic included in this study.

Lamiaceae family

Initially, this family was known as Labiatae; it comprises 236 genera and 7,173 identified species and ranks sixth in terms of diversity globally, being one of the families with the most species in Mexican territory (Martínez-Gordillo *et al.*, 2017; Mena, Silva & Medina, 2020). According to Mena *et al.* (2020), Lamiaceae family members are characterized by high amounts of essential oils with antibacterial activity and potential value in medicine. In the Lamiaceae family, we can find aromatic and medicinal herbs such as peppermint (*M. piperita*), oregano (*O. vulgare)*, basil (*O. basilicum*), and rosemary (*R. officinalis*), (Martínez-Gordillo *et al*., 2017).

Peppermint

The plant, known as mint, peppermint, or *M.* x *piperita* L., is a hybrid of *M. spicata* L. and *M. aquatica*. It is an aromatic herb valued for its essential oil, which can be extracted from various plant tissues. Peppermint is a perennial plant with a quadrangular shape, reaching a height of 50 to 90 cm. It thrives in sunny areas and can grow in acidic, neutral, or basic soils and clay (Singh, Shushni & Belkheir, 2015). While its cultivation dates back to ancient Egypt, it is now grown globally, with significant cultivation in Europe, North America, and North Africa (Mahendran & Rahman, 2020).

The entire plant, including its flowers and leaves, contains essential oils that are used for medicinal purposes. Peppermint essential oil treats digestive disorders and stomach discomforts, such as heartburn, gastritis, bile, constipation, and intestinal infections (López-Martínez, Chan-Jiménez, López & Rodríguez-Luna, 2023).

Several studies have highlighted the antibacterial properties of peppermint essential oil (Table I), (Alhaithloul *et al.*, 2019; Marjanović-Balaban *et al*., 2018; Singh *et al.*, 2015). In experiments, peppermint essential oil inhibited the growth of *L. monocytogenes* (+), *P. aeruginosa* (-), *E. coli* (-), *S. enterica* (-), and *S. aureus* (+), with inhibition grew zones of 32.33 mm, 12 mm, 21 mm, 27.33 mm, and 37.66 mm, respectively (Table I**)**. Notably, the essential oil's activity against *L. monocytogenes* (+) and *S. aureus* (+) was found to be more effective than the antibiotics used in the study (amoxicillin, doxycycline, ciprofloxacin, streptomycin, and gentamicin), (Marjanović-Balaban *et al.*, 2018).

Another study showed that essential oil extracted from the aerial parts of *M. piperita* at the start of the flowering stage exhibited antimicrobial activity against *Bacillus cereus* (+) with a MIC of 0.25 μL/mL and a minimal lethal concentration (MLC) of 64 μL/mL. *Staphylococcus mutans* (+) had a similar MIC to *B. cereus* but lower essential oil resistance with an MLC value of 0.25 μL/mL. Among the gram-negative pathogens, *Klebsiella pneumoniae* (-) was more sensitive to peppermint oil extract (MIC of 0.25 μL/mL and MLC of 0.5 µL/mL) compared to *Shigella flexneri* (-) and *Shigella dysenteria* (-) (MIC and MLC of 0.5 μL/mL), (Table I), (Mahboubi & Kazempour, 2014). Peppermint oil also demonstrated synergistic activity with the antibiotics vancomycin, gentamycin, and amphotericin B, with a fractional inhibitory concentration (FIC) index of less than 0.5, suggesting the potential to reduce the dosage of antibacterial agents and the risk of antimicrobial resistance (Mahboubi & Kazempour, 2014). Antibacterial activity of peppermint essential oil from leaves was also observed against *S. aureus* (+) and *E. coli* (-) at 100 mg/mL of essential oil. *S. aureus* and *E. coli* presented an inhibition zone of 7.6 mm, respectively (da Silva Ramos *et al.*, 2017). Singh *et al.* (2015) found that *S. aureus* exhibited greater susceptibility than *E. coli* at 0.5% peppermint essential oil. The MIC for the bacterial species was 0.5% and 0.7%, respectively (Table I).

Secondary metabolites such as menthol, menthone, iso-menthone, 1,8-cineole, carvone, piperitone, and caryophyllene oxide were identified in peppermint essential oil. Menthol (36.9% to 70.08%), the main compound, together with menthone (14.49% to 28.8 %) and caryophyllene oxide (1.87 to 2.96%), seems to contribute to the overall antimicrobial activity of the oil (Figure 1a, Table I), (Camele, Gruľová & Elshafie, 2021; Mahboubi & Kazempour, 2014; Marjanović-Balaban *et al.*, 2018). Peppermint essential oil affects the structure of bacterial cell walls by altering their permeability and the concentration gradients of hydrogen (H^+) and potassium (K^+) ions. This leads to the impairment of essential cell processes such as electron transport, protein translocation, and oxidative phosphorylation, ultimately causing loss of osmotic control and cell death (da Silva Ramos *et al.*, 2017; Marjanović-Balaban *et al.*, 2018).

Oregano

Oregano (*O. vulgare*) is a perennial herbaceous plant with woody stems that can reach 20 to 80 cm in height. It produces pink or purple flowers grouped in spikes. This plant is native to the Mediterranean region and prefers dry, well-drained soils (Oniga *et al.*, 2018). Turkey is the world's primary producer of oregano, with exports exceeding 10,000 tons annually, followed by Mexico, Greece, and other countries (Meléndez, Camargo, Meza, Sepúlveda, Santos & Parra, 2017).

Traditionally, oregano leaves, stems, or flowers are used to prepare infusions and treat respiratory, gastric, and gynecological conditions. Oregano is also used to treat cough and chest discomfort in cases of fever, improve digestion and relieve cramps, including menstrual cramps, combat dysmenorrhea, and prevent abortion (Sharma *et al.*, 2017).

Oniga *et al.* (2018) evaluated the antimicrobial activity of ethanolic extracts of the aerial parts of oregano against *L. monocytogenes* (+), *S. aureus* (+), *E. coli* (-), and *S. enteritidis* (-). *S. aureus* and *E. coli* presented an inhibition zone of 16 mm. In comparison, *S. enteritidis* and *L. monocytogenes* presented an inhibition zone of 18 mm and 17 mm, respectively, all lower than the control antibiotic gentamicin. Regarding MIC, *S. enteritidis* and *S. aureus* presented a value of 78.13 µg/mL compared to 625 µg/mL of the 70% ethanol control. *E. coli* and *L. monocytogenes* presented a similar MIC of 156.25 µg/mL compared to 2500 µg/mL and 1250 µg/mL of the 70% ethanol control (Oniga *et al.*, 2018). A significant dose-dependent antibacterial activity of the ethanolic extract of oregano leaves against *S. aureus* has also been observed. At 80 mg/mL, the inhibition zone was 21.64 mm (Table I), (Pérez-Delgado, Alvarado-Pineda & Yacarini-Martínez, 2021).

Phenolic compounds (gentisic acid, chlorogenic acid, *p*-coumaric and rosmarinic acid) and flavonoids (hyperoside, isoquercitrin, rutin, quercitrin, quercetin and luteolin) were identified in the extract of the aerial parts of oregano. These compounds contribute to oregano extract´s antioxidant, antimicrobial, anti-inflammatory, hepatoprotective, and neuroprotective capacity (Table I), (Oniga *et al.*, 2018). Specifically, the antibacterial activity of oregano extract has been attributed to the high content of polyphenols (flavonoids and phenolic acids). Other reports indicated that the phenolic compounds carvacrol and thymol are responsible for the antibacterial activity of oregano essential oil (Figure 1a), (Soltani, Shakeri, Iranshahi & Boozari, 2021). The phenolic compounds can alter the bacteria´s cell membrane and cell wall permeability. This process triggers the release of cellular components and eventually causes the death of the bacteria (Oniga *et al.*, 2018; Soltani *et al.*, 2021).

Basil

Basil (*O. basilicum*) is an annual plant recognized for its genetic diversity. It originates from Asia but is cultivated worldwide due to its economic value. Basil grows in tropical, subtropical, and temperate regions (Purushothaman, Prasanna, Suganthi, Ranganathan, Gimbun & Shanmugam, 2018). The leaves of basil are used in cooking, and its essential oils are used in the personal hygiene products industry. Traditionally, basil is used to treat infections in the mouth and skin and conditions of the bladder, kidneys, and scalp. Additionally, it is used to treat issues such as pimples, hair loss, ascariasis, scorpion stings, varicose veins, and heart conditions (Sharma *et al.*, 2017).

Basil essential oil has been recognized for its antioxidant and antimicrobial capacity (Stanojevic *et al.*, 2017; Varga, Carović-Stanko, Ristić, Grdiša, Liber & Šatović, 2017). The essential oil of basil exhibited antimicrobial activity against various gram-positive bacteria (*S. aureus*, coagulase-positive *Staphylococcus*, *Streptococcus* group D, *B. cereus*, *L. monocytogenes*), and gram-negative (*E. coli*, *S. enterica*, *Salmonella* spp., *P. aeruginosa*, and *Providencia stuartii*) bacteria. However, the most prominent inhibition was observed in coagulase-positive *Staphylococcus*, which presents an inhibition zone of 40 mm (Table I). For some bacterial strains, the antimicrobial activity of essential oil was even superior to the antibiotics ciprofloxacin and gentamicin (Stanojevic *et al.*, 2017). In another study, the essential oil extracted from basil leaves generated an inhibition zone range of 29.20 to 30.56 mm for *S. aureus*, 10.66 to 16.11 mm for *B. cereus*, and 17.24 to 23.58 mm for *E. coli*. *P. aeruginosa* did not show growth. As for the MIC value, *E. coli* and *P. aeruginosa* showed greater sensitivity to the essential oil, ranging from 9 to 18 µg/mL values, compared to 18 to 36 µg/mL for *S. aureus* and *B. cereus* (Table I). Interestingly, the essential oil presented better results than the antibiotic tetracycline in gram-negative bacteria (*E. coli* and *P. aeruginosa*), (Moghaddam, Shayegh, Mikaili & Sharaf, 2011). The essential oil of basil leaves also inhibits the growth of the gram-negative bacteria *S. enteritidis* with MIC values of 20 µg/mL (Rattanachaikunsopon & Phumkhachorn, 2010).

Stanojevic *et al.* (2017) identified 65 components in basil essential oil, of which linalool (31.6 %) and methyl chavicol (23.8 %) are the majority compounds. The essential oil also found compounds such as (E)-caryophyllene, α-humulene, terpineol, eugenol, thymol, β-selinene, carvacrol, and linalool (Table I). The antibacterial activity has been attributed to the high content of terpenes such as linalool; one hypothesis suggests that the hydroxyl group of eugenol could generate reactions with proteins, hindering enzymatic activity and causing the

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death of the bacteria (Figure 1a), (Amor *et al.*, 2021; Bassolé *et al.*, 2010; Ilić *et al.*, 2021). Something interesting observed in basil is that the development, growth stages, and growth conditions can influence the essential oil´s composition, quality, and antibacterial properties (Ilić *et al.*, 2021; Moghaddam *et al.*, 2011).

Rosemary

Rosemary (*R. officinalis* L.) is an aromatic, perennial, branched, needle-shaped shrub that reaches a height of 0.8 to 1.0 m. The trunk´s bark is generally gray. Native to the Mediterranean and Asia, it is cultivated in temperate regions around the world. The sessile, blue flowers are grouped in 5 to 10, forming a dense, broom-shaped cluster (Avila-Sosa, Navarro, Vera, Dávila-Márquez, Melgoza-Palma & Meza-Pluma, 2011).

The most common medicinal uses of rosemary include treating digestive system conditions such as stomach pain, indigestion, gallbladder problems, ulcers, diarrhea, irritation, gastritis, colitis, flatulence, appendix conditions, and stomach inflammation (Sharma *et al.*, 2017).

Elyemni *et al.* (2022) reported the antimicrobial activity of the essential oil of two rosemary chemotypes growing under different climatic conditions against gram-positive (*S. aureus* and *B. subtilis*) and gram-negative bacteria (*E. coli* and *P. aeruginosa*). The results showed a range of MICs for chemotype I from 0.315 to 1.25 mg/mL and for chemotype II from 2.5 to 5 mg/mL for all bacteria tested. Chemotype I presented the highest antimicrobial activity, suggesting that the compounds present in the oil may vary depending on the collection region (Elyemni *et al.*, 2022). In another study, the antibacterial activity of rosemary essential oil showed MIC and minimum bactericidal concentration (MBC) values of 0.625% and 1.25% for *S. aureus* and 1.25% and 2.5% for *E. coli*, respectively (Table I), (Jafari-Sales & Pashazadeh, 2020).

The essential oil of rosemary leaves has antimicrobial properties due to certain compounds present in it: hydrocarbon monoterpenes such as α-pinene; oxygenated monoterpenes such as 1,8 cineole, linalool, borneol, and camphor; and sesquiterpenes such as β-caryophyllene and α-caryophyllene (Elyemni *et al.*, 2022). The most abundant compound found in cultivated rosemary was α-pinene (15.40%), followed by 1,8-cineole (32.18%) and camphor (16.20%), (Elyemni *et al.*, 2022). Similarly, rosemary essential oil contains 19 compounds, with 1,8 cineole and α-pinene found in higher proportions (Table I), (Jafari-Sales & Pashazadeh, 2020). Santoyo, Cavero, Jaime, Ibañez, Señoráns & Reglero, 2005) reported the antimicrobial activity of α-pinene, 1,8-cineole, camphor, verbenone, and borneol identified in rosemary essential oil. Borneol, camphor, and verbenone were found to be more effective than α-pinene, 1,8-cineole (Figure 1a).

It is noted that gram-negative bacteria tend to have greater resistance to rosemary essential oil, which could be attributed to forming an outer membrane surrounding the cell wall. This membrane prevents the diffusion of the essential oil's hydrophobic compounds.

Asteraceae family

The Asteraceae family is one of the most prominent plant families, encompassing around 20,000 species, including trees, shrubs, and herbaceous plants. Except for Antarctica, this family is distributed worldwide (Pretel, Sánchez, Pérez & Obón, 2008). In Mexico, plants from this family can be found in diverse habitats such as dunes, coastal regions, and snowy mountains (Villaseñor, 2018). Mexico has a rich flora of Asteraceae, with 122 genera and 477 species. Some well-known plants from this family in Mexico include Mexican arnica (*H. inuloides* Cass.) calendula (*C. officinalis* L.), and Marigold (*T. erecta* L.), which are known for their antibacterial properties (Ortiz-Bermudez *et al.*, 1998; Sotero-García, Gheno-Heredia, Martínez-Campos & Arteaga-Reyes, 2016).

Mexican arnica

Mexican arnica (*H. inuloides* Cass.) is an herbaceous perennial plant that can reach a maximum height of 50 cm. Its leaves are simple and alternate, around 10 to 12 cm long. The flowers are dimorphic with a diameter ranging from 2.5 to 4 cm. This plant has a wide distribution in Mexico, mainly in Michoacán, Puebla, and Zacatecas. The significant presence of the plant in different geographical regions reflects its importance in the Mexican Republic (Rodríguez-Chávez *et al.*, 2017).

Mexican arnica has been traditionally used to treat various conditions, such as rheumatism, topical inflammation of the skin, muscle pain, and gastrointestinal disorders. The leaves and flowers are commonly used to make infusions, decoctions, and topical applications. It is also utilized as an ointment and antiseptic for treating skin wounds (Rosas-Piñón, Mejía, Díaz-Ruiz, Aguilar, Sánchez-Nieto & Rivero-Cruz, 2012; Sharma *et al.*, 2017).

In the hexanoic extract of Mexican arnica flowers, certain sesquiterpenoids such as 7-hydroxy-3,4-dihydrocadalin, β-caryophyllene, 7-hydroxycadalin, and β-caryophyllene-4, 5α-oxide have been found. These compounds demonstrated antimicrobial properties against the gram-positive bacteria *B. subtillis*, *S. mutans*, *S. aureus*, *B. ammoniagenes*, and *P. acnes*. Seven-hydroxy-3,4-dihydrocadalin and 7-hydroxycadalin exhibited potent antimicrobial activity against all gram-positive bacteria with a MIC range of 6.25 to 12.5 µg/mL, with *P. acnes* being the most sensitive to sesquiterpenes with a MIC of 6.25 µg/mL (Figure 1b, Table II), (Kubo *et al.*, 1994). This may explain the traditional use of arnica in treating acne. In another study, organic arnica extract showed potent antibacterial activity

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against *S. aureus* (+) and *E. coli* (-), with inhibition zones ranging from 0.2 cm to 1.5 cm. GC/MS analysis of organic arnica extract demonstrated the presence of the sesquiterpenoids 7-hydroxycadalene, caryophyllene, and δ-cadinene (Table II), (García-Pérez, Cuéllar-Bermúdez, Arévalo-Gallegos, Rodríguez-Rodríguez, Iqbal & Parra-Saldivar, 2016). The results strongly suggest that Mexican arnica extract's antibacterial activity is attributed to sesquiterpenes.

Calendula

C. officinalis L., also known as mercadela or calendula, is an ornamental perennial plant that belongs to the Asteraceae family and can reach a height of 20 cm to 40 cm. It is characterized by yellow to orange flowers, and various parts of the calendula plant are utilized for medicinal purposes. Calendula has been traditionally used as an anti-inflammatory for the skin, as a healing agent, and for treating wounds or burns. It is also attributed to antipyretic, antiepileptic, and antimicrobial properties (Ak *et al.*, 2021; Arora, Rani & Sharma, 2013; Çetin, Kalyoncu & Kurtuluş, 2017).

Research has shown that the essential oil of calendula flowers exhibits a stronger antibiotic effect against gram-negative bacteria than gram-positive bacteria (Arora *et al.*, 2013; Janssen, Chin, Scheffer & Baerheim, 1986). For instance, at a concentration of 0.5 mg/mL, *C. officinalis* essential oil generated more potent inhibition on *E. coli* (-) (13.31 ± 1.24 mm) and *P. aeruginosa* (-), (10.22 ± 0.83 mm) than in *S. aureus* (+) (3.14 ± 0.27 mm), (Chaleshtori, Kachoie & Pirbalouti, 2016). Similarly, calendula essential oil produced inhibitions in the growth zones of 10.3, 11, and 12.7 mm for *E. coli* (-), *B. subtilis* (+), and *S. aureus* (+), respectively (Table II) (Arora *et al.*, 2013; Janssen *et al.*, 1986).

The phytochemical analysis of the essential oils of calendula flowers revealed that they contain a significant content of 1,8-cineole (30.456%), as well as terpenoids such as γ-terpinene (25.547%), terpinolene (4.584%), α-terpineol (4.490%), and trans-β-ocinene (4.153%). Minor concentrations of eugenol, α-pinene, β-caryophyllene, carvacrol, and (E)-caryophyllene were also found (Chaleshtori *et al.*, 2016). Moreover, a total of 53 common compounds, including α-cadinol, α-pinene, β-caryophyllene, and caryophyllene oxide, were identified in the essential oils of both the flowers and leaves of *C. officinalis* (Ak *et al.*, 2021). These compounds may be responsible for the antibacterial properties of the essential oil of *C. officinalis*.

Furthermore, other calendula extracts have also demonstrated antimicrobial activity. Ethanol and chloroform extracts of *C. officinalis* calli from leaf explants showed inhibition zones ranging from 8 to 38 mm against gram-positive and gram-negative bacteria. The ethanolic extract of *C. officinalis* callus showed the largest inhibition zone of 38 mm against *S. aureus*, while the extract with chloroform showed a 32 mm inhibition zone against *B. cereus* (Table II). The inhibition zones for each bacterial strain were similar to those generated by the antibiotics used in the study (penicillin, novobiocin, ampicillin, chloramphenicol, and erythromycin), (Çetin *et al.*, 2017). The phytochemical analysis of aqueous, ethanolic, and chloroform extracts indicated the presence of alkaloids, carbohydrates, flavonoids, terpenoids, sterols, and tannins (Chakraborthy, 2008). Notably, flowers' ethanolic extract exhibited antibacterial properties attributed to oxygenated triterpenes (Ramos, Edreira, Vizoso, Betancourt, López & Décalo, 1998). However, the leaf oil extract of calendula showed even more significant antibacterial activity compared to other leaf extracts. In particular, the leaf oil ether extract exhibited larger inhibition zones in the growth of *B. subtilis* (+), *E. coli* (-), *S. lutea* (+), and *K. pneumoniae* (-) bacteria than the chloroform extract (Shahen *et al.*, 2019).

Marigold

As it is known in Mexico, the marigold or flower of the dead (*T. erecta* L.) is an annual, erect, branched, and herbaceous plant that can reach up to 1.8 m in height. It has round stems and orange or yellow ray flowers. It is native to Mexico and grows wild in San Luis Potosí, Chiapas, Puebla, Sinaloa, Tlaxcala, and Veracruz. The plant is cultivated as an ornamental plant worldwide. In Latin America and Africa, it is marketed for the yellow dye (lutein) that can be extracted from its flowers (Lim, 2013).

The marigold has been used in traditional medicine for centuries. Its leaves are used as an antiseptic agent for kidney disorders and muscle pain, while the flowers are used for fever, epileptic conditions, and stomach problems. The plant's dye is also used for treating colds and rheumatism (Rakholiya & Chanda, 2012; Shetty, Sakr, Al-Obaidy, Patel & Shareef, 2015).

Studies have shown that marigold has antibacterial properties. The aqueous extract of *T. erecta* leaves showed inhibitory effects on ten gram-positive and six gram-negative bacteria strains. The maximum inhibitory effect was observed against *Acinetobacter baumannii* (-) with an activity index of 0.9133, followed by *P. acnes* (+) and *Streptococcus pneumoniae* (+), which presented activity indexes of 0.9066 and 0.02666, respectively (Table II), (Dasgupta, Ranjan, Saha, Jain, Malhotra & Saleh, 2012). These findings suggest that marigold" could be used to develop drugs against skin diseases like dermatitis, acne, and skin sores or as an antiseptic (Dasgupta *et al.,* 2012). Another study found that marigold petal extract inhibited the growth of gram-positive bacteria *Streptococcus agalactiae* (7.67, 9.5, and 12 mm) in a concentration-dependent manner (25, 50 , and 75 mg/mL), (Table II), (Mekvimol, Poonthong, Chaipunna & Pumipuntu, 2020).

The effectiveness of marigold's antibacterial properties varies depending on the solvent's polarity and the bacterial species.

Padalia & Chanda (2015) evaluated the antibacterial activities of flower extracts obtained with hexane, toluene, ethyl acetate, acetone, methanol, and water against gram-positive and gram-negative bacteria. The acetone extract showed the most significant inhibitory effect. For gram-positive (*B. cereus*, *B. subtilis*, *S. aureus*, *S. albus*, *L. monocytogenes*) and gram-negative bacteria (*Pseudomonas pseudoalcaligenes*, *P. morganii*, *P. aeruginosa*, *K. pneumoniae*, *P. mirabilis*) the MIC and MBC values ranged from 78 to 1250 µg/ml and 312 to 1250 µg/mL, respectively (Table II). Additionally, a synergistic effect was observed between the acetone extract and the commercial antibiotic ceftazidime against *B. subtilis* (+) and *P. aeruginosa* (-), with FIC values of 0.312 and 0.093, respectively.

The phytochemical analysis of *T. erecta* flower extract showed that it contains a high amount of alkaloids and flavonoids and a moderate presence of tannins, triterpenes, and cardiac glycosides (Table II). Plants that have these compounds are known to have antibacterial properties. It has been suggested that the antimicrobial effect of *T. erecta* extracts is due to combining all these components (Padalia & Chanda, 2015). Flavonoids mainly target the cell membrane in bacteria but also affect DNA gyrase, an essential enzyme in DNA replication (Yan *et al.*, 2024).

Malvaceae family

Plants of the Malvaceae family are widely distributed in tropical, subtropical, and temperate regions. This family includes herbaceous species, subtrees, and even large trees. It has more than 115 genera and more than 2,000 identified species, of which 413 varieties are native to Mexico (Robles-Valdivia & Sánchez-Otero, 2022). Malvaceae family is characterized by having dicotyledonous flowers; the leaves are simple, palmate, serrated, and rarely entire (Xu & Deng, 2017). Some species of this family, such as roselle (*H. sabdariffa*), cocoa (*T. cacao*), and cotton (*G. hirsutum*), are widely used in the agri-food industry. These plants are also used in traditional Mexican medicine (De Lima, Oliveira, Carneiro, Lima, Coutinho & Morais-Braga, 2021; Sharma *et al.*, 2017).

Roselle

The roselle plant (*H. sabdariffa*), also named hibiscus or karkade, is a perennial annual plant that grows in tropical and subtropical regions, including China, Egypt, Indonesia, Mexico, Nigeria, Thailand, and Saudi Arabia. The intense red color of the calyces is due to the high anthocyanin content. Roselle is used in traditional medicine to relieve stomach discomfort, poor digestion caused by excessive intake, and fever caused by colds (Riaz & Chopra, 2018). Other properties include diuretic, choleretic, analgesic, antitussive, antihypertensive, immunomodulatory, hepatoprotective, antioxidant, anticancer, and antibacterial activity (Izquierdo-Vega *et al.*, 2020).

Portillo-Torres *et al.* (2019) found that the acetone extract of roselle calyces had antibacterial activity against eight multidrug-resistant *Salmonella* (-) strains and pathogenic *E. coli* (-) strains isolated from food. All bacteria presented zones of inhibition ranging from 10.3 to 12.6 mm. *Hibiscus* acid identified in the acetone extracts exhibited higher antibacterial activity than the crude acetone extract against all *Salmonella* and *E. coli* strains (10.3 to 16 mm), (Figure 1c). For *Salmonella* and *E. coli* strains, hibiscus acid caused MIC and MBC values of 4 to 7 mg/mL and 5 to 7 mg/mL, while for acetone extract values of 7 mg/mL and 10 mg/mL, respectively (Figure 1c, Table III). Hibiscus acid can alter the permeability of the cell membrane, leading to bacterial cell death (Portillo-Torres *et al.*, 2019). Another study demonstrated the antibacterial activity of the aqueous extract of *Hibiscus* calyces. The MIC for *S. aureus* (+) and *Streptococcus faecalis* (+) was 0.5 mg/mL, and for *E. coli* (-), *K. pneumoniae* (-), and *Salmonella typhi* (-) was 1.0 mg/mL (Table III), (Navarro García *et al*., 2006). It has also been suggested that the high content of flavonoids, terpenoids, and anthocyanins in the calyces is responsible for the antibacterial activity against gram-positive and gram-negative bacteria (Izquierdo-Vega *et al.*, 2020; Sharma *et al*., 2017).

The antibacterial activity of roselle leaves and stems has been demonstrated in several studies. For instance, the methanolic extract of roselle leaves showed antimicrobial activity at concentrations of 2.5, 5, and 10% against *E. coli* strains isolated from diverse sources, including clinical isolates. The highest inhibition zone (12.66 mm) was observed at 10% (Fullerton, Khatiwada, Johnson, Davis & Williams, 2011). Even the resistant *S. typhi* (-) strain presented an inhibition zone of 19 mm at 200 mg/mL of the ethanolic extract of leaves, with MIC and MBC values of 12.5 mg/mL and 25 mg/mL, respectively. When the extract was combined with ciprofloxacin, the MBC was reduced to 0.097 mg/mL (Table III), (Balali, Yar & Sylverken, 2023). Kumar and Sheba (2019) obtained similar results with methanolic extracts of roselle leaves and stems against *S. aureus* (+) and *P. aeruginosa* (-). Additionally, a synergetic effect of the extract and the antibiotic chloramphenicol against *S. aureus* was observed (Kumar & Sheba, 2019).

The presence of various compounds in the ethanolic extracts of roselle leaves, such as alkaloids, phenols, saponins, tannins, triterpenoids, and coumarins, has been suggested to contribute to their antibacterial activity (Table III), (Balali *et al.*, 2023).

Cocoa

Cocoa (*T. cacao*) is a perennial plant native to Mesoamerica that grows in shady environments. Its fruit is of utmost importance for the chocolate industry. This crop represents an agro-biological legacy transmitted by the Mesoamerican culture (Ramírez-Guillermo, Lagunes-Espinoza, Ortiz-García, Gutiérrez & Rosa-Santamaría, 2018).

In traditional medicine, cocoa is widely used. It is an expectorant for pulmonary congestion and treating asthma and bronchitis.

The cocoa rind also treats bladder, kidney, and liver infections and diabetes (Olaleye & Ogunbiyi, 2022; Phillips, 2023).

The 30% crude cocoa extract exhibited strong antibacterial activity against both clinical isolates of gram-positive and gram-negative bacteria, surpassing the control antibiotic ciprofloxacin. The extract produced an inhibition zone ranging from 33 to 30 mm in gram-positive bacteria (*S. aureus*, *S. epidermidis*, *S. saprophytics*, and *S. pyogenes*) and from 37 to 30 mm in gram-negative bacteria (*K. pneumonia*, *P. merabilis*, *P. vulgaris*, *S. typhimurum*, and *S. typhi*), (Table III), (Al-Shalah *et al.*, 2022). Similarly, the crude cocoa pod husk extract showed antimicrobial activity against *S. aureus* (+) with a MIC of 0.62 mg/mL (Indrianingsih, Wulanjati, Windarsih, Bhattacharjya, Suzuki & Katayama, 2021). Ramadhanie *et al.* (2020) found that the MBC of the ethanolic extract of cocoa bark against *S. pyogenes* (+) was 12.5%. These results indicate that cocoa extract has great potential for clinical treatment of both gram-positive and gram-negative bacteria.

Analysis of the chloroform extract of cocoa steam bark identified the presence of alkaloids, tannins, saponins, glycosides, carboxylic acids, and flavonoids (Olaleye & Ogunbiyi, 2022). The identified metabolite acids (tannins, saponins, glycosides, phenols, flavonoids, and alkaloids) demonstrated antimicrobial activity against *E. coli* (31 mm), *S. pneumonia* (30 mm), *S. aureus* (27 mm) and *P. aeruginosa* (30 mm**)**, (Table III), (Olaleye & Ogunbiyi, 2022). It is suggested that the presence of alkaloids and flavonoids creates an alkaline environment, leading to protein coagulation and eventual alteration of cell wall components such as peptidoglycan, resulting in bacterial death (Olaleye & Ogunbiyi, 2022; Ramadhanie *et al.*, 2020).

Cotton

Cotton (*G. hirsutum* L.) is a plant cultivated for industrial purposes, used primarily for its fiber in the textile industry and for oil production from its seeds. Mexico is one of the top worldwide producers of cotton, with cultivation mainly in the states of Tamaulipas, Baja California, Sonora, Chihuahua, and Durango (Robles-Valdivia & Sánchez-Otero, 2022). In traditional Mexican medicine, cotton has been used to treat respiratory ailments like coughs and asthma. Additionally, cotton has been employed as an analgesic for pain relief and treating gastrointestinal diseases such as dysentery and diarrhea (Al-Snafi, 2018). Traditionally, the leaves are consumed as tea, but they can also be applied locally as a healing agent (Delgado *et al.*, 2019).

Krishnaveni, Dhanalakshmi & Nandhini (2014) found that the ethanolic extract of cotton seeds exhibited concentration-dependent inhibition against *E. coli* (-) and *S. aureus* (+). Both *E. coli* and *S. aureus* were inhibited at 50 µg/mL and 100 µg/mL concentrations. At 100 µg/mL, the largest zone of inhibition (20 mm) was observed for both bacteria. The activity shown by the seeds is attributed to the phytochemical content, particularly saturated and unsaturated fatty acids (Table III), (Krishnaveni *et al.*, 2014).

Extracts obtained from other tissues of the cotton plant also demonstrated antibacterial activity. Rojas, Lévaro, Tortoriello & Navarro (2001) assessed hexanoic, chloroformic, and methanolic extracts of cotton leaves against *S. aureus* (+), *S. pneumoniae* (+), *S. pyogenes* (+), *Enterococcus faecalis* (+), and *E. coli* (-). The hexane extract exhibited MIC values ranging from 1.2 to 5 mg/mL for all bacteria, while the chloroform and methanolic extracts showed MIC values from 2.5 to 5 mg/mL (Table III), (Rojas *et al.*, 2001). In a separate study, Iyevhobu *et al.* (2022) found that the chloroform extract of cotton leaves presented the highest inhibitory activity against *P. fluorescens* (-), while the methanolic extract of the same tissue was more effective against *E. coli*. The ethanolic extract of cotton also showed moderate antimicrobial potential against the gram-negative bacteria *K. pneumoniae* and *E. coli*; for both bacteria, the MIC was 1024 µg/mL (Delgado *et al.*, 2019). Miranda, Santana, Machado, Coelho & Carvalho (2013) reported that the ethanolic extract of leaves exhibited activity against *S. aureus* (+) at 200 mg/mL and 500 mg/mL, generating maximum inhibition zones of 8 and 10 mm, respectively (Table III).

The phytochemical analysis of an aqueous and ethanolic extract of cotton (leaves, inflorescence, and stem) revealed the presence of reducing sugars, phenolic compounds, alkaloids, coumarins, flavonoids, saponins, tannins, and triterpenes (Table III), (Miranda *et al.*, 2013). Additionally, it has been suggested that the antibacterial properties of cotton are attributed to triterpenes, tannins, and flavonoids (De Lima, 2021).

Conclusions

Medicinal plants exhibiting antibacterial activity are a valuable source of compounds with therapeutic potential for combating gram-positive and gram-negative pathogenic bacteria in humans. Research into the antibacterial properties of plants contributes to scientific advancement and can significantly impact public health by providing therapeutic options and practical solutions.

The selection of plant tissue, the harvesting period, and the choice of solvent are crucial for obtaining maximum antibacterial activity, as they can influence the composition and effectiveness of plant extracts. It is important to note that the antibacterial activity of plant extracts also depends on the targeted bacterial species.

Interestingly, combining essential oils or plant extracts with commercial antibiotics has been observed to have a synergistic effect on several species of bacteria; this has the potential to improve the effectiveness of antibiotics alone and combat drug-resistant bacteria and specific pathogens. It also offers an alternative approach to reducing antibiotic dosage and provides valuable information on new therapies to combat antibiotic resistance. The active compounds with antibacterial activity produced by plants are diverse and include essential oils, alkaloids, phenolic compounds, flavonoids, terpenes, sesquiterpenes, and alcohols. Furthermore, these compounds act on bacteria through different mechanisms, and in many cases, it remains to be seen whether they act individually or in combination. The antimicrobial activity of only a few compounds, such as hibiscus acid, α-pinene, 1,8-cineole, borneol, and camphor, has been evaluated individually. Therefore, more studies are needed to identify and isolate the specific active compounds responsible for this antibacterial activity. Finally, conducting more *in vivo* studies in humans is essential to confirm the antibacterial activity of medicinal plants and their mechanisms of action *in vivo*.

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Conflict of interest

The authors declare that they have no conflict of interest.

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