Iranian Journal of Pharmaceutical Sciences
2026: 22 (1): 488- 500
https://journals.sbmu.ac.ir/IJPS

Research Article

OPEN ACCESS

Phytochemical and Antibacterial Evaluations of *Lantana camara* L. and Its Interaction with Garamycin

Hasan Alauldeen Khalaf [a,b,*], Ruaa Aziz Jassim [a], Mohammed Khalid Abbood [c], Khulood S. Salim [d], Ali Khalaf Hasan [e], Omid Alizadeh [f], Vahid Reza Askari [f,*]

[a] *Department of Pharmacognosy, College of Pharmacy, Al-Bayan University, Baghdad, Iraq.*
[b] *Department of Pharmacognosy and Medicinal Plants, College of Pharmacy, Mustansiriyah University, Baghdad, Iraq.*
[c] *Department of Clinical Pharmacy, College of Pharmacy, Al-Bayan University, Baghdad, Iraq.*
[d] *Department of Pharmacology and Toxicology, College of Pharmacy, Al-Bayan University, Baghdad, Iraq.*
[e] *Department of Clinical and Laboratory Sciences, College of Pharmacy, Al-Bayan University, Baghdad, Iraq.*
[f] *Patient Safety Research Center, Clinical Research Institute, Mashhad University of Medical Sciences, Mashhad, Iran.*

Received: March 14, 2025 **Accepted:** August 2, 2026 **Available online:** November 15, 2026.

Abstract

The increasing challenge of antibacterial drug resistance has increased efforts to find new antibacterial agents from plants. The chemical composition and antimicrobial activity of *Lantana camara*, a plant known for its abundance of active compounds, were investigated. Methanol and n-hexane extracts of *Lantana camara* leaves, along with the isolated glycoside acteoside, were tested against *Bacillus cereus*, *Escherichia coli*, *Pseudomonas*, and *Staphylococcus aureus* using agar well diffusion, minimum inhibitory concentration (MIC), and minimum bactericidal concentration (MBC) assays. The n-hexane extract was further analyzed by gas chromatography–mass spectrometry (GC–MS). Both extracts showed clear zones of inhibition, mainly against *B. cereus* and *E. coli* (13–14 mm), with MICs as low as 0.2 mg/mL, while Garamycin (Gar) showed even higher potency (MIC 0.002 mg/mL). The acteoside showed significant activity against *B. cereus* and *E. coli* (MIC 0.4 mg/mL; MBC/MIC ≤2), confirming its antibacterial activity in the plant. However, it was only bacteriostatic against *S. aureus* and showed no effect against *P. aeruginosa*. Importantly, both crude extracts and acteoside showed synergistic effects with Gar, with fractional inhibitory concentration (FIC) indices ≤0.5, indicating their potential as antibiotic adjuvants. The GC–MS analysis of the n-hexane extract identified bioactive compounds, such as palmitic acid, oleic acid, isomers of octadecenoic acid (an indole derivative), and terpenoid hydrocarbons, which are potentially disruptive to bacterial membranes and metabolic pathways. These results reveal that *L. camara* exhibits excellent broad-spectrum antibacterial activity through synergistic phytochemicals; hence, it can be considered a promising source for developing topical antibacterial agents and a natural preservative alongside antibiotics.

Keywords: Acteoside; Antibacterial Activity; GC-MS; *Lantana camara*; Verbascoside; Synergistic Effect.

*** Corresponding Authors**:
Hasan Alauldeen Khalaf, Department of Pharmacognosy, College of Pharmacy, Al-Bayan University, Baghdad, Iraq. E-mail: hasan.alaa@albayan.edu.iq.
Vahid Reza Askari, Patient Safety Research Center, Clinical Research Institute, Mashhad University of Medical Sciences, Mashhad, Iran. E-mail: vahidrezaaskary@gmail.com; askariv@mums.ac.ir.

Cite this article as: Alauldeen Khalaf H., Aziz Jassim R., Abbood M. Kh., Salim Kh.S., Hasan A.Kh., Alizadeh O., Askari V.R. Phytochemical and Antibacterial Evaluations of *Lantana camara* L. and Its Interaction with Garamycin. Iran. J. Pharm. Sci., 2026, 22 (1): 488- 500.

DOI: https://doi.org/10.22037/ijps.v22i1.47832

This open-access article is distributed under the terms of the Creative Commons Attribution Non Commercial 4.0 License (CC BY-NC 4.0).

1. Introduction

The rising epidemic of antimicrobial resistance (AMR) poses a significant danger to global public health, diminishing the efficacy of traditional antibiotics and requiring the immediate development of new treatment approaches [1]. A possible method of combating AMR is combination therapy, which involves using classical antibiotics together with natural products as adjuvants to achieve greater effectiveness without being circumvented by resistance mechanisms or creating opportunities for the emergence of new ones [2, 3]. This potential synergistic effect can enhance the antibacterial activity and can potentially restore susceptibility in pathogens that have developed resistance to monotherapy [4].

Lantana camara L. (Verbenaceae) is a common and widespread shrub having different medicinal properties against tumors, chickenpox, measles, ulcers, asthma, inflammation, dermatitis, hypertension, bilious fever, infectious diseases, malaria, tetanus, diabetes, and rheumatism [5]. *L. camara* has been used in traditional medicine for the treatment of infections and wounds since ancient times [6]. This ethnobotanical significance is substantiated by scientific data validating its abundant array of bioactive phytochemicals, including monoterpenes (e.g., limonene, sabinene, eucalyptol, and β-phellandrene), sesquiterpenes (e.g., β-caryophyllene, bicyclo germacrene, davanone, nirolidol, and germacrene), triterpenes mainly lantadene (A, B, C, and D), iridoid glycosides, flavonoids, phenylethanoid glycosides, steroids, and oligosaccharides were isolated from *L. camara* [7, 8]. Acteoside (act), also known as verbascoside, is the principal phenylpropanoid extracted from *L. camara* [9]. There is evidence to suggest that acteoside exhibits marked antimicrobial, anti-inflammatory, and antioxidant effects, and studies have suggested the likelihood of it acting upon bacterial cell walls [10-12]. The reported antibacterial activity of *L. camara* extracts warrants further investigation in combination therapies, as one of the leading candidates based on the observed results.

The intrinsic antibacterial effects of *L. camara* are acknowledged [13], but the synergistic effects of its phytochemicals with other antibiotics have been little investigated. Resistance: Often due to enzymatic modification, resistance is increasingly eroding the value of garamycin (Gar), an aminoglycoside antibiotic that is important to combat severe Gram-negative infections [14]. Agents derived from plant sources, such as acteoside, could jeopardize bacterial membrane permeability, thereby enhancing Gar intracellular accumulation and evading important resistance mechanisms [15]. Accordingly, this study systematically investigates the antibacterial potential of an *L. camara* extract and its isolated compound, acteoside, against four clinically important bacterial strains. The most important goal in this case is to study their antibacterial activity and possible synergism with Gar. We hypothesize that the antibacterial activities of herbal extracts and acteoside synergize with Gar by increasing bacterial membrane permeability, thereby potentiating Gar's effects and offering a viable strategy to extend its clinical value against various resistant pathogens.

2. Materials and Methods

2.1. Plant Material and Chemical Compounds

The plant was collected from the gardens of Al-Bayan University, Baghdad, Iraq, from February to March 2022, after being recognized by Prof. Dr. Ibrahim S.A. A voucher specimen was deposited (no. 89/15123) in the Iraqi National Herbarium. The acteoside standard was obtained from Adooq Bioscience LLC, California, USA. All solvents were obtained from Fisher Scientific, UK, and BDH Chemicals, UAE.

2.2. Weight Determination of Dry Extract

L. camara leaves were dried in the oven at 45 °C directly after collection, then the plant was powdered and weighed (10 g) using a sensitive balance (5 digits), then leaves were extracted by Soxhlet's apparatus using n-hexane (250 mL) and then methanol (250 mL) as extracting solvents for 4 hr at 65℃ (boiling point of methanol is 64.7℃) [16].

2.3. Phytochemical Tests

To find secondary metabolites in the extracts of *L. camara* leaves, specific qualitative tests were carried out for different plant extracts (methanol, ethyl acetate, and n-hexane). Mayer's test was used to detect alkaloids, and

This open-access article is distributed under the terms of the Creative Commons Attribution Non Commercial 4.0 License (CC BY-NC 4.0).

the Liebermann test was used to detect phytosterols. Sterols were tested by adding 3 mL of acetic anhydride and 3 mL of concentrated sulphuric acid to 0.5 g of ethyl acetate extract. Phenolic compounds were tested by adding 1 mL of ferric chloride to 1 mL of the plant extract. The presence of tannins was detected by boiling 1 g of dried, powdered leaves in 10 mL of distilled water (DW), then adding ferric chloride and leaving it undisturbed for observation. Flavonoids act as weak acids and form phenoxide salts in a basic medium, which is colored, and the color disappears upon addition of dilute acid. Saponins were tested by decocting 1 g of leaf powder with 50 mL DW. Then, 3 mL of the extract was diluted with 3 mL of DW in a test tube and vigorously shaken. Bornträger's test was used to detect anthraquinones. Baljet's test was used to detect cardiac glycosides, which were then treated with the sodium picrate reagent. Terpenoids were tested by Salkowski's test, by dissolving the sample in chloroform, followed by the addition of concentrated H_2SO_4. The presence of iridoid glycosides was tested by using the Trim-Hill reagent (1 mL of copper (II) sulfate pentahydrate and 8 mL acetic acid with 0.5 mL concentrated HCl).

2.4. Extraction of Acteoside

Dried powdered leaves (10 g) were extracted by Soxhlet's apparatus using absolute methanol (0.5 L) for 4 hr after defatting with n-hexane for 1.5 hr. The extract was dried using a rotary vacuum evaporator and then dissolved in distilled water (30 mL). This solution was transferred to a separatory funnel and partitioned with ethyl acetate (30 mL) three times. After that, the ethyl acetate extract was dried by a rotatory vacuum evaporator. The dried ethyl acetate extract was kept at 4℃ until used for detection and isolation procedures.

2.5. Detection and Isolation of Acteoside by TLC

The presence of acteoside was detected using an analytical thin-layer chromatography (TLC) plate (4 × 10 cm, 0.20 mm thickness). Three solvent systems were used, including system A, which consists of ethyl acetate**:** methanol**:** water (7.5:1.6:0.9) [17], system B, which consists of ethyl acetate: water: formic acid (10:3:2), and system C that consists of ethyl acetate: methanol: water (100 ml: 16.5 ml: 13.5 ml) in comparison with standard acteoside [18, 19]. In the case of preparative TLC (15 × 15 cm, 0.25 mm thickness), system A was used as a mobile phase for the isolation of acteoside.

2.6. Liquid Chromatography-Mass Spectroscopy Analysis of Acteoside

The isolated acteoside from *L. camara* has been stored in a high-performance liquid chromatography (HPLC) vial until use. LC-MS analysis was performed in the Ministry of Science and Technology in Iraq; the stationary phase is a zorbox ods column (150 × 4.5 mm) with 5 µm thickness, the mobile phase is acetic acid in water (0.1%) and acetic acid in acetonitrile (0.1%) to a flow rate of up to 0.30 ml/min, with 25 minutes running time; the injection vol was 8 µL at ambient temp. The mass detector was a triple quadrupole operating in ESI mode, set to isolate the acteoside fragments at different mass-to-charge ratios; the full scan was performed over the m/z range of 100-700 Daltons. The pressure of the nebulizer was 60 psi N_2 at 12L/min; the voltage of the fragmenter was set at 70V, and the capillary voltage was 4200V.

2.7. Gas Chromatography-Mass Spectrometry Analysis

Powdered leaves (1 g) were macerated by n-hexane (10 mL), then reserved for 24 hr at 25 ℃. After filtration, the filtrate was centrifuged for 5 min. The supernatant was then placed in a beaker, allowed to evaporate and dry, and stored at 4°C in a GC-MS-certified vial until used for GC-MS analysis. The chromatograph used was a Shimadzu GC-QP 2010; the injector and interface temperatures were set to 290 ℃; the column type was a phenyl-arylene column (25 m × 0.2 mm, 0.25 µm). The temperature was programmed at 65℃ for 6 min, then increased to 160℃ with a hold time of 6 min, then raised to 260℃; this column is nonpolar and cross-linked and can be washed and stand high temp; it consists of 5% phenyl 95% dimethyl polysiloxane through which helium gas moved with a flow rate of about 1.30 mL/min, transporting the extract components along the column toward the detector, which is quadrupole detector using 70 eV potential for ionizing the chemicals by electrons impact.

This open-access article is distributed under the terms of the Creative Commons Attribution Non Commercial 4.0 License (CC BY-NC 4.0).

2.8. Antibacterial Assay

Dried leaves powder (5 g) was macerated in methanol (20 ml). After two days of maceration at 25 ℃, the methanol extract was washed with 20 mL of n-hexane (×3), and then the n-hexane layers were discarded. Another 5 g of leaves were macerated in n-hexane (20 mL), then reserved for 2 days, washed with 20 mL of methanol (×3), and the methanol layers were discarded. After filtration, the obtained filtrates were centrifuged for 7 minutes. The supernatants were then placed in beakers to evaporate and dry, and then stored at 4°C. The extracts were dissolved in 1-4 mL (w/v) of dimethyl sulfoxide (DMSO) just before evaluating the antibacterial activity [20].

Staphylococcus aureus (FRI1169), *Bacillus cereus* (LA2007), *Escherichia coli* (E2348/69), and *Pseudomonas aeruginosa* (K767) were used in this assay and were collected from the National Chemical Laboratory, Baghdad, Iraq. The strains were kept in nutrient agar at 3°C. Each type of bacterium was placed in a 10 mL sterile nutrient broth in conical flasks. After that, a digital shaker incubator was used to incubate the conical flasks under aerobic conditions at 37℃ for 19 hours to stimulate bacterial growth. Then, the inocula were diluted with saline solution until they reached the McFarland no. turbidity. 0.5 standard (10^8 CFU/mL) [21].

According to the National Committee for Clinical Laboratory Standards, the agar well diffusion method was used to assess the bacterial inhibition zone of *L. camara* products, including methanol extract (ME), n-hexane extract (HE), and acteoside [22]. A sterile cotton swab was immersed in the bacterial solution and then streaked uniformly across the Mueller-Hinton agar plate to create a consistent inoculum. A sterilized borer (7 mm) was used to drill holes in the seeded plates, and the plates were then allowed to dry for 5 minutes. A sterile micropipette was used to inject 100 µL of sample (100 mg/mL) of ME, HE, acteoside, positive control (Gar, 0.4 mg/mL), and negative control (DMSO) into the bores and allowed to diffuse through the medium and incubated for one day at 37℃ (**Figure 1**). The experiment was performed three times, and the mean values were determined.

The iodonitrotetrazolium chloride (INT) colorimetric test was used to determine the MIC of the herbal samples and Gar against the bacteria considered. Indeed, INT is originally yellow and is reduced by viable bacteria to an insoluble formazan, which is purple-pink in color [23]. Mueller-Hinton Broth/DMSO was used as a solvent for all samples. DMSO (2%) was mixed with Mueller-Hinton Broth, and serial dilutions (twofold) were made with the highest and lowest concentrations of 0.134 and 0.00026 mg/mL of Gar, 3.2 and 0.0062 mg/mL of AE, HE, and acteoside. After that, 100 μL of inoculum (5×10^5 CFU/mL) was added to each well of a 96-well plate. The plate contents were mixed with a plate agitator, then incubated for 20 hr at 37°C. The test was performed three times. The negative control was prepared with INT (0.25 mg/mL), DMSO (2%), and sufficient broth (100% growth). After the incubation period, INT (45 μL) at 0.25 mg/mL was added to each well, and the plate was incubated for 45 min at 37°C. A color change from yellow to purple-pink indicates the reduction of INT by viable bacteria [24].

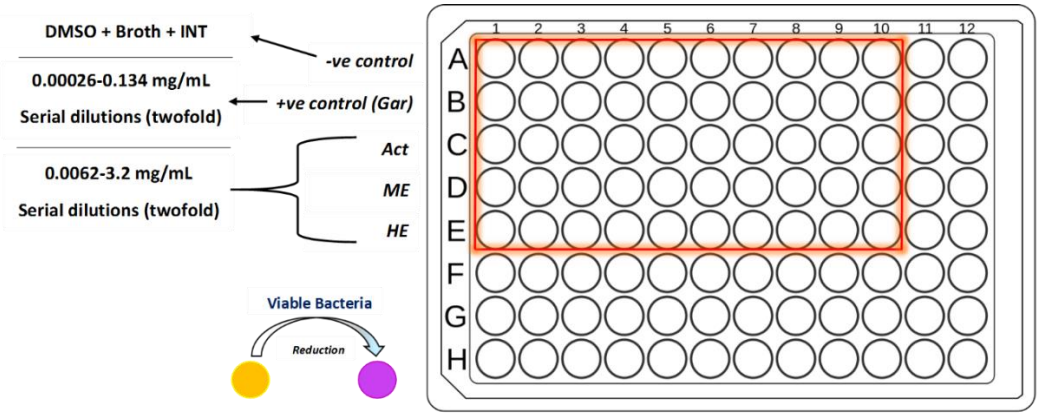


Figure 1. Description of the antibacterial method using a 96-well plate. Methanol extract (ME), n-Hexane extract (HE), Acteoside (Act), Garamycin (Gar).

This open-access article is distributed under the terms of the Creative Commons Attribution Non Commercial 4.0 License (CC BY-NC 4.0).

All MIC values were converted to $\log_2$ MIC (n=3) before calculating standard deviations (±SD). To determine MBC, an aliquot (10 µL) from the wells that showed no color change was seeded in nutrient agar plates. The negative control well was also seeded after dilution (1:1000) to obtain a final concentration of 500 CFU/mL. The number of colonies was counted using the colony counter, then the original CFU/mL in the test well was calculated by multiplying the number of colonies by the dilution factor (equal to 1 for the undiluted aliquot) and dividing by the volume plated in mL (original CFU/mL in the well = colonies counted × dilution factor/volume plated in mL). MBC is determined by a 99.9% kill threshold (≤ 500 CFU/mL). The plates were incubated overnight at 37°C. MBC has the lowest concentration of antibacterial compounds and can kill more than 99.9% of bacteria [25].

The checkerboard technique was used to evaluate the antibacterial activity of the natural products of *L. camara* (ME, HE, and acteoside). The synergistic effect of these natural products was assessed using a 96-well plate. Mueller-Hinton Broth (100 µL) was dispensed into the plate wells using a multichannel pipette. The suspensions of inocula were prepared in Mueller-Hinton Broth and diluted with sterile saline to obtain inocula of 10^8 CFU/mL according to a half McFarland standard. This was vortexed and diluted to achieve the final inoculum concentration (5×10^5 CFU/mL) [26]. Then, antibacterial A (Gar) and antibacterial B (one of the herbal products) were dispensed (100 µL) into the wells according to the checkerboard technique [27]. The concentrations used were MICs that were reduced by three twofold serial dilutions: MIC/2, MIC/4, and MIC/8 for the herbal products, and MIC/4, MIC/8, and MIC/16 for Gar. Thus, the wells of each row contain constant concentrations of antibacterial A, with increasing concentrations of antibacterial B, and vice versa, which holds for each column in the plate. After that, the plate was inoculated by dispensing the inoculum (100 µL) into each well, which was incubated for 20 hr at 37℃. The calculation of fractional inhibitory concentration (FIC) of compound A (e.g. ME, Gar or others) can be calculated as MIC of compound A in the mixture / MIC of compound A alone, while FIC index= FIC_A + FIC_B, the results were interpreted as following: synergistic effect (≤0.5), weak interaction (0.5-0.99), indifferent effect (1 to 4), or antagonistic effect (>4) [28, 29]. All tests were performed in triplicate.

3. Results and Discussion

3.1. Dry Extract Weight and Phytochemical Tests

The weight of dry extract from 10 g of powdered leaves was 1.95 g (19.5% w/w) of methanol extract and 0.85 g (8.5% w/w) of *n*-hexane extract. Various phytoconstituents, including alkaloids, saponins, terpenes, flavonoids, phenolic compounds, cardioglycosides, and phytosterols, were detected (**Table 1**). Different studies have shown that the phytochemical profile of *L. camara* is defined by several principal chemical types. These comprise phenylpropanoid glycosides, including verbascoside; terpenoids, which encompass iridoid glycosides like theveside and triterpenes (e.g., lantadene A and B); and flavonoids such as luteolin and its derivatives [30]. Other plant components include phenolic acids, alkaloids, and volatile oils, which enhance its unique scent [31].

Table 1. The chemical constituents in extracts of powdered leaves of Iraqi *L. camara*.

Phytoconstituents	Positive indicator	Methanol	Ethyl acetate	n-hexane
Flavonoids	Yellow color	+	+	-
Phenolic compounds	Purple color	+	+	-
Anthraquinones	Pink-rose color	-	+	-
Terpenoids	Brown interface	+	-	+
Alkaloids	White-creamy ppt.	+	+	-
Saponins	Persistent foam	+	-	+
Tannins	Dark color (green or blue)	+	+	-
Cardioglycosides	Yellow to orange color	+	+	-
Steroids	Green color	-	+	+
Iridoids	Light blue	+	-	-

Note: +=found, -=not found

This open-access article is distributed under the terms of the Creative Commons Attribution Non Commercial 4.0 License (CC BY-NC 4.0).

3.2. TLC and LC-MS Analysis of Acteoside

The acteoside isolated from *L. camara* has been analyzed by TLC using its standard in three mobile phases, as documented in the literature (**Table 2**).

Table 2. TLC chromatogram.

Mobile phase	Retardation factor (R_f)	
	Sample	Standard
System A	0.61	0.61
System B	0.63	0.62
System C	0.54	0.55

Preparative TLC with the mobile phase (system A) was an acceptable method for isolating acteoside from the ME of *L. camara*, yielding 58.7 mg of acteoside per 1 g of dry leaves. Mass spectrometry showed that the TLC-isolated compound is acteoside (**Figure 2**).

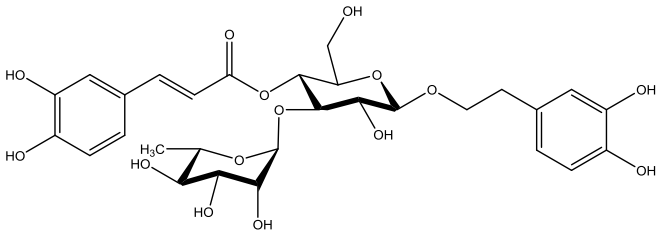


Figure 2. Chemical structure of acteoside.

The mass-to-charge ratio at 623 amu (precursor ion) represents a loss of a proton $[M-H]^-$ from the molecular ion. A basic peak at *m/z* 477 is due to the loss of a hexosyl residue (146 amu) from the precursor ion, which created the ion at *m/z* 323 after the consequent neutral loss of the hydroxytyrosyl group (154 amu). Similarly, the peak at 461 amu results from the neutral removal of 162 amu from the precursor ion following its rearrangement. Finally, the peak at 161 amu represents the rhamnose ion (**Figure 3**). The acteoside structure and mass fragmentation are shown in **Figures 2** and **3**, respectively.

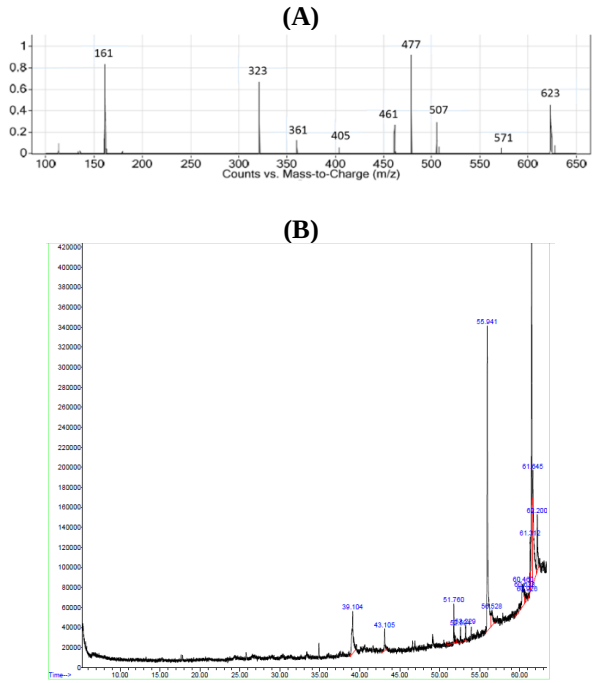


Figure 3. A) Mass spectrum of acteoside, and B) Total ion chromatogram (TIC) of the GC-MS of *L. camara*

3.3. Chemical Constituents of n-Hexane Extract

In the present GC–MS analysis of the HE of *L. camara*, some alkanes, terpenoids, and fatty acid components were recognized. This is reliable with recent studies, which is found that the leaf's oil is rich in fatty acids – mainly oleic (cis-9-octadecenoic) acid and palmitic (hexadecanoic) acid [32], in addition to other reported compounds like mono- and sesquiterpenes in *L. camara* HEs, including sabinene, 3-carene, 1,8-cineole (eucalyptol), terpinen-4-ol, cadinols, β-caryophyllene and menthol derivatives [33]. The phytochemical constituents of HE are shown in **Table 3**, along with their retention times (RTs).

Table 3. Active constituents in HE of *L. camara* leaves.

Active constituent	Type	RT (min)	Area%
Pentadecane	Alkane	39.1	6.75
Hexadecane	Alkane	43.1	1.81
Neophytadiene	Diterpene	51.7	1.57
1H-Indole-2,3-dione, 6,7-dimethoxy	Alkaloid	52.6	1.60
2,6-dimethyl- 2,6-Octadiene	Alkene	53.2	1.07
Palmitic acid	Fatty acid	55.9	25.97
Thiosulfuric acid	Sulfur oxoacid	56.5	2.73
Oleic Acid	Fatty acid	60.4	6.23
Naphthol	Phenolics	60.6	1.10
Menthol	Monoterpene	61.0	1.01
(Z)-9-Octadecenoic acid	Fatty acid	61.3	3.82
9,12-Octadecadienoic acid	Fatty acid	61.5	25.88
(E)-9-Octadecenoic acid	Fatty acid	62.2	15.75

This open-access article is distributed under the terms of the Creative Commons Attribution Non Commercial 4.0 License (CC BY-NC 4.0).

In our data, we likewise detected menthol and both Z- and E-9-octadecenoic acids (the cis- and trans-forms of oleic acid), along with 1H-indole-2,3-dione derivatives and other terpenoids. Fatty acids like oleic and palmitic acid have known antibacterial properties – for instance, oleic acid has been shown to inhibit Gram-positive pathogens by disrupting membranes [34, 35]. Thus, the GC–MS profile suggests that the hexane fraction of *L. camara* contains lipophilic agents capable of compromising bacterial cell envelopes and metabolism. In particular, compounds such as β-caryophyllene and related terpenes (found in our extract and in the literature) are reported to exert their effects on membranes and biofilms. Menthol, which can increase bacterial membrane permeability, would complement the acteoside's mode of action [36, 37].

Overall, the GC–MS findings corroborate that both primary metabolites (fatty acids) and secondary metabolites (terpenoids, indoles) contribute to the extract's activity. The high abundance of unsaturated fatty acids (oleic acid ~20–37% and palmitic acid ~7–15% in recent reports) [32] likely enhances membrane-targeting effects [38], while terpenes add further antimicrobial potency. This complex chemical profile underscores why crude extracts can exceed the activity of any single isolated compound: multiple constituents can act on different bacterial targets simultaneously [39].

3.4. Determination of Antibacterial Activities

The present work demonstrated that extracts from *L. camara* leaves and acteoside inhibit Gram-positive and Gram-negative bacteria. This aligns with various recent reports of antibacterial properties of *L. camara* extracts. The studies demonstrated that *L. camara* leaf extracts suppress *E. coli*, *S. aureus*, Providencia vulgaris, *Vibrio cholerae*, *P. aeruginosa*, *Bacillus* species, and other pathogens [40, 41]. In our study, both the polar (ME) and nonpolar (HE) extracts produced inhibition zones (around 13–14 mm against *E. coli* and *B. cereus*), as shown in **Figure 4** and **Table 4**, and low MICs (0.2 mg/mL), as shown in **Figure 5** and **Table 5**. These activity levels align with previous disk-diffusion experiments; for instance, a recent study found that the ethanolic extract of *L. camara* produced inhibition zones of ~6–9 mm against *S. aureus* and *P. aeruginosa* (with an MIC ≈150 µg/mL) [42].

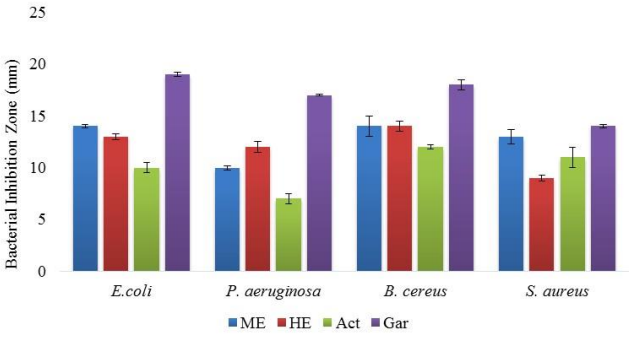


Figure 4. Mean bacterial inhibition zones of Methanol extract (ME), n-Hexane extract (HE), Garamycin (Gar), and acteoside (Act) against the tested bacterial strains (Mean ± SD).

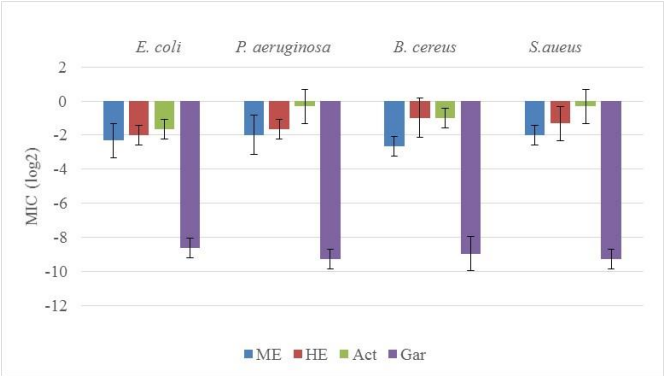


Figure 5. Antimicrobial activity of *L. camara* extracts and acteoside (Act) expressed as $\log_2$(MIC), (Mean ± SD). Methanol extract (ME), n-Hexane extract (HE), Garamycin (Gar).

Table 4. Bacteria inhibition zone.

Microorganism	Bacteria Inhibition zone (mm)			
	Methanol extract	n-Hexane extract	Acteoside	Garamycin
E. coli	14 ±0.17	13 ±0.3	10 ±0.5	19 ±0.2
P. aeruginosa	10 ±0.2	12 ±0.5	7 ±0.5	17 ±0.1
B. cereus	14 ±1	14 ±0.5	12 ±0.2	18 ±0.5
S. aureus	13 ±0.7	09 ±0.3	11 ±1	14 ±0.2

This open-access article is distributed under the terms of the Creative Commons Attribution Non Commercial 4.0 License (CC BY-NC 4.0).

Table 5. Mean log_2 of MIC.

Mean log2 of MIC				
Microorganism	**Methanol extract**	**n-Hexane extract**	**Acteoside**	**Garamycin**
E. coli	-2.32 ± 1.00 (0.2)	-1.99 ± 0.58 (0.2)	-1.65 ± 0.58 (0.4)	-8.64 ± 0.58 (0.002)
P. aeruginosa	-1.99 ± 1.15 (0.4)	-1.65 ± 0.58 (0.4)	-0.32 ± 1.00 (0.8)	-9.30 ± 0.58 (0.002)
B. cereus	-2.65 ± 0.58 (0.2)	-0.99 ± 1.15 (0.4)	-0.99 ± 0.58 (0.4)	-8.97 ± 1.00 (0.002)
S. aureus	-1.99 ± 0.58 (0.2)	-1.32 ± 1.00 (0.4)	-0.32 ± 1.00 (0.8)	-9.30 ± 0.58 (0.002)

Data presented as Mean ± standard deviation (SD) of mean log2 (n=3). Number between brackets = MIC.

Conspicuously, acteoside showed apparent antibacterial activity. In our tests, acteoside inhibited *E. coli* and *B. cereus* (MIC 0.4 mg/mL, MBC 0.8 mg/mL, respectively) and was bactericidal (MBC/MIC ≤2); however, against *S. aureus*, it was only bacteriostatic. It had comparatively lower activity against *P. aeruginosa* (**Figure 6** and **Table 6**). This behavior is consistent with the literature on acteoside, which reports antibacterial activity against various bacteria (including *E. coli*, *S. aureus*, *and Klebsiella species*) [43]. Acteoside was exclusively bacteriostatic against *S. aureus* and less active against *P. aeruginosa* in our experiments, which may indicate a need for additional compounds in the extract to fully exert its activity against different organisms. In conclusion, acteoside is an active antibacterial agent of *L. camara*; its greater efficacy in the crude extract indicates synergistic or additive effects of other phytochemicals. The MIC result leads to an important pharmacological finding: the crude extracts of *L. camara* repeatedly demonstrated higher potency than the separated constituent, acteoside. This is reflected in the mean log_2 (MIC) values of ME and HE relative to act across most bacteria.

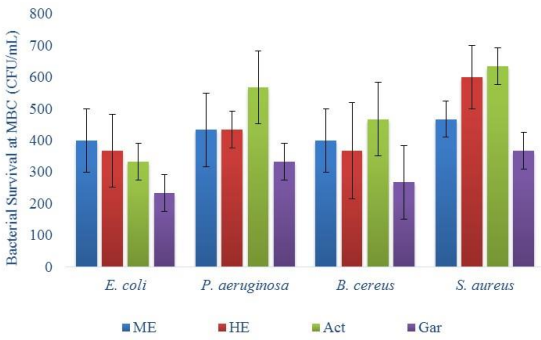


Figure 6. Bactericidal activity of Methanol extract (ME), n-Hexane extract (HE), Garamycin (Gar), and acteoside (Act) represented by bacterial survival at MBC (CFU/mL), (Mean ± SD).

The observed vulnerability is consistent with previously described resistance profiles of the bacterium. The lowest susceptibility to all treatments—due to its extremely impermeable outer membrane, enzymatic defense mechanisms, and efflux pumps was displayed by *P. aeruginosa* [44]. On the other hand, both plant extracts and acteoside (low MICs coupled with differences in MBCs) were effective against Gram-positive *B. cereus* and Gram-negative *E. coli*, whereas the Gram-positive *S. aureus* showed intermediate resistance. This hierarchy is in line with previously reported data; for example, as described by a number of accounts, *L. camara* has greater efficacy against *E. coli* and *Bacillus* when compared to *P. aeruginosa* [42]. The variability highlights the importance of testing against different pathogens and indicates that some resistant species, like *P. aeruginosa*, may need higher doses or additional therapies [45]. Testing against a different bacterium is important, and the diversity indicates that certain resistant species may need higher doses or complementary treatments. As anticipated, the MICs (µg/mL range) of Gar were significantly lower than those of the plant extracts, indicating the greater potency of a pure medication. Nonetheless, the suppression of Gram-variable microorganisms by natural extracts at mg/mL concentrations indicates that *L. camara* could be a valuable source of antibacterial leads.

The antibacterial activity of *L. camara* probably arises from a complex mixture of secondary metabolites. Phytochemical studies consistently identify phenolics, alkaloids, saponins, glycosides, flavonoids, and terpenoids in *L. camara* [42]. In particular, methanol extracts are rich in polar phenolic and glycosidic compounds (such as acteoside), while nonpolar extracts (n-hexane extracts) concentrate terpenoids, steroids, and fatty acids.

This open-access article is distributed under the terms of the Creative Commons Attribution Non Commercial 4.0 License (CC BY-NC 4.0).

Table 6. Bacterial survival at MBC.

Microorganism	Bacterial Survival at MBC (CFU/mL)			
	Methanol extract	n-Hexane extract	Acteoside	Garamycin
E. coli	400 ±100 (0.8)	367 ±115 (0.8)	333 ±58 (0.8)	233 ±58 (0.033)
P. aeruginosa	433 ±116 (0.8)	433 ±58 (1.6)	567 ±116 (-)	333 ±58 (0.067)
B. cereus	400 ±100 (0.4)	367 ±153 (0.4)	467 ±116 (1.6)	267 ±116 (0.033)
S. aureus	467 ±58 (1.6)	600 ±100 (-)	633 ±58 (-)	367 ±58 (0.134)

Data presented as Mean ± Standard Deviation of bacterial survival in CFU/mL calculated from triplicate colony counts (n=3). Number between brackets = MBC (mg/mL)

According to reports, the acteoside itself weakens bacteria and frequently converts bacteriostatic exposure into bactericidal effects (as we saw with *E. coli* and *B. cereus*). It also disrupts bacterial membranes, inhibits biofilm formation, and inhibits enzymes [12, 46]. Indeed, entire extracts can occasionally surpass any single pure ingredient due to the synergy of various chemical classes; phenolics, terpenoids, and other constituents work together to extend the target profile and aid in overcoming resistance [47]. Acteoside alone was only bacteriostatic in our tests, whereas the polar extract killed *S. aureus* bactericidally at higher doses (MBC/MIC ≤ 2), indicating that additional extract constituents (possibly flavonoids or terpenoids) enhanced its bactericidal activity.

The impact of synergistic effects with FIC indices ranged from 0.37 to 0.75, fluctuating with bacterial type and the concentration of each antibacterial. MIC/8 was the lowest concentration that had a synergistic effect, with 0.0005 mg/mL of Gar. The ME was found to have the most synergistic activity towards all tested bacteria. In the HE case, greater potential synergism with Gar was observed with *B. cereus*, whereas with *P. aeruginosa*, it was less pronounced. Nonetheless, the synergistic capacity was lower than that of ME and HE. Although acteoside displayed a lower synergistic activity than ME and HE. While it showed synergism at MIC/4 against *E. coli*, acteoside did not exhibit synergism against *P. aeruginosa* and had no effect at MIC/8, as shown in **Table 7** and **Figure 7**. This indicates that these herbal products can potentiate Gar activity, likely by augmenting membrane permeability or decreasing bacterial efflux. Such synergy is pharmacologically valued, as it may reduce the essential antibiotic dose while enhancing efficacy. These findings place *L. camara* not only as a direct antimicrobial source but also as a potential adjuvant in combination therapy.

4. Conclusion

The escalating crisis of antibiotic resistance requires the investigation of an unconventional treatment approach. Our research conclusively identifies *L. camara* as a potential source of antibacterial compounds, exhibiting substantial inhibitory effects against the tested bacteria in both ME and HE. Meanwhile, the identification and bactericidal activity of acteoside, and GC–MS results showing a complex phytochemical composition with antimicrobial terpenoids and fatty acids in hexane extracts, emphasize the important utility of this plant, i.e., the supply of individual-specific lead compounds as well as complex synergistic mixtures at different levels. This work confirmed the concept of phytochemical diversity of *L. camara* as a source of resistance against microorganisms. The subsequent phases entail bioassay-guided fractionation to identify additional active compounds, thorough examination of synergies with traditional antibiotics to enhance their effectiveness, and extensive toxicological profiling to determine the therapeutic index. By translating these phytochemical insights into practical applications, *L. camara* extracts or isolated compounds, such as acteoside, hold significant potential for advancement as antibiotic adjuvants, topical antiseptics, or food preservatives, thereby contributing meaningful approaches to the global arsenal against AMR.

This open-access article is distributed under the terms of the Creative Commons Attribution Non Commercial 4.0 License (CC BY-NC 4.0).

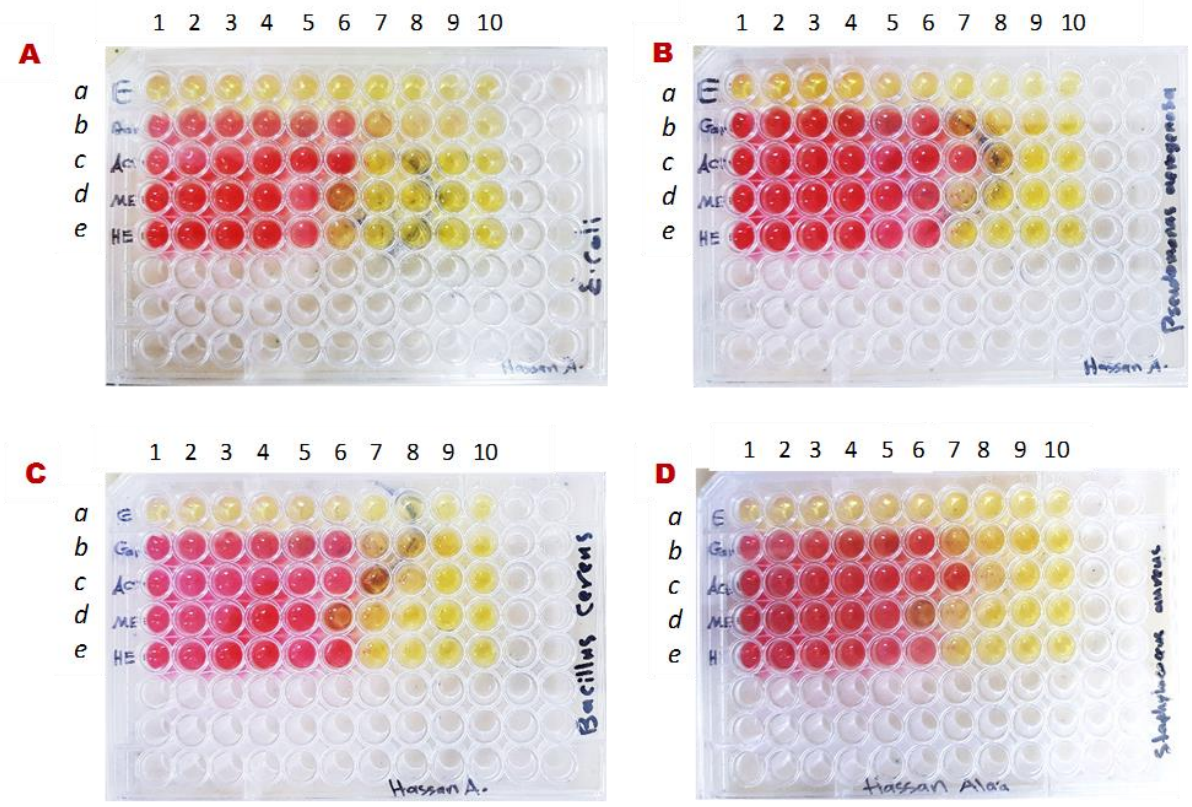


Figure 7. Minimum inhibitory concentration: a, b, c, d, and e are –ve control, Garamycin (Gar), acteoside(Act), Methanol extract (ME), n-Hexane extract (HE), respectively. (A) *E. coli* plate with MIC of b7, c7, d6 and e6; (B) *P. aeruginosa* plate with MIC of b7, c8, d7 and e7; (C) *B. cereus* plate with MIC of b7, c7, d6, and e7; (D) *S. aureus* plate with MIC of b7, c8, d6 and e7

Table 7. Synergism between *L. camara* products and garamycin.

Sample		MIC of Gar in the mixture (mg/mL)			
		E. coli	***P. aeruginosa***	***B. cereus***	***S. aureus***
Methanol extract	MIC/2	0.0005 (0.75)^{W}	0.0005 (0.75)^{W}	0.0005 (0.75)^{W}	0.0005 (0.75)^{W}
		0.00025 (0.62)^{W}	0.00025 (0.62)^{W}	0.00025 (0.62)^{W}	0.00025 (0.62)^{W}
		0.000125 (0.56)^{W}	-	0.000125 (0.56)^{W}	-
	MIC/4	0.0005 (0.5)^{S}	0.0005 (0.5)^{S}	0.0005 (0.5)^{S}	0.0005 (0.5)^{S}
		0.00025 (0.37)^{S}	-	-	-
	MIC/8	0.0005 (0.37)^{S}	-	0.0005 (0.37)^{S}	0.0005 (0.37)^{S}
n-Hexane extract	MIC/2	0.0005 (0.75)^{W}	0.0005 (0.75)^{W}	0.0005 (0.75)^{W}	0.0005 (0.75)^{W}
		0.00025 (0.62)^{W}	-	0.00025 (0.62)^{W}	-
	MIC/4	-	-	0.0005 (0.5)^{S}	0.0005 (0.5)^{S}
	MIC/8	-	-	0.0005 (0.37)^{S}	-
Acteoside	MIC/2	0.0005 (0.75)^{W}	-	0.0005 (0.٧٥)^{W}	0.0005 (0.75)^{W}
		0.00025 (0.62)^{W}	-	-	-
	MIC/4	0.0005 (0.5)^{S}	-	-	-

Between brackets = FIC index, S = synergistic, W = weak synergism

Our results unambiguously show that acteoside is not the only molecule accounting for the full antibacterial profile of the plant, a concept broadly described in phytochemistry. The enhanced coverage in the crude extracts indicates that some components of *L. camara* interact synergistically. In the future, it would be beneficial to investigate acteoside combinations with co-occurring substances or conventional antibiotics, and to isolate more active molecules (such as terpenoid glycosides, extra flavonoids, or indole derivatives) using bioassay-guided fractionation. Comprehensive mechanistic studies (e.g., membrane integrity dyes,

This open-access article is distributed under the terms of the Creative Commons Attribution Non Commercial 4.0 License (CC BY-NC 4.0).

efflux pump inhibition tests, biofilm quantification) might elucidate the synergistic mechanisms of these drugs. Lastly, cytotoxicity testing is essential for assessing safety and establishing treatment indices. Overall, our findings align with an expanding body of literature that acknowledges *L. camara* extracts as multifaceted antibacterials, with their effectiveness stemming from the synergistic interactions among fatty acids, phenolics, glycosides, and terpenoids.

Acknowledgment

The authors are thankful to Al-Bayan University for financial support throughout this scientific research.

Conflict of interest

The authors proclaim no conflict of interest.

Data availability

The original contributions presented in this study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author(s).

Authors Contributions

Hasan Alauldeen Khalaf: Conceptualization, funding acquisition, supervision, and writing – review & editing. **Ruaa Aziz Jassim**: Investigation, and writing – original draft. **Mohammed Khalid Abbood**: Formal analysis, investigation, and software. **Khulood S. Salim**: Investigation, and writing – original draft. **Ali Khalaf Hasan**: Investigation, and writing – original draft. **Omid Alizadeh**: Investigation, and writing – original draft. **Vahid Reza Askari**: Conceptualization, data curation, methodology, and writing – review & editing.

Authors' ORCID numbers

Hasan Alauldeen Khalaf: 0000-0003-2334-9427
Ruaa Aziz Jassim: 0000-0001-7240-0204
Mohammed Khalid Abbood: 0000-0002-0727-3576
Khulood S. Salim: 0000-0003-1349-5500
Ali Khalaf Hasan: 0000-0001-9349-3913
Omid Alizadeh: 0000-0003-0854-905X
Vahid Reza Askari: 0000-0001-9268-6270

Funding

The authors are thankful to Al-Bayan University for financial support.

Using artificial intelligence chatbots

During the preparation of this manuscript, the authors used **the free version of Google Gemini** primarily for language editing, grammar improvement, and readability enhancement. These tools were applied selectively during the drafting of the Introduction, Methods, and Discussion sections to assist with sentence structure and clarity. After using these tools, the authors thoroughly reviewed, verified, and revised all content to ensure scientific accuracy, originality, and adherence to the manuscript's factual and analytical integrity. The authors take full responsibility for the integrity and final content of the published article.

Declaration of Authors

The authors proclaim that the study in this article is original and that any issues with claims related to its content will be their responsibility.

References

1. Ho CS, Wong CT, Aung TT, Lakshminarayanan R, Mehta JS, Rauz S, et al. Antimicrobial resistance: a concise update. Lancet Microbe. 2025;6:100947.
2. Kaspute G, Zebrauskas A, Streckyte A, Ivaskiene T, Prentice U. Combining Advanced Therapies with Alternative Treatments: A New Approach to Managing Antimicrobial Resistance? Pharmaceutics. 2025;17(5):648.
3. Morales-Duran N, Leon-Buitimea A, Morones-Ramirez JR. Unraveling resistance mechanisms in combination therapy: a comprehensive review of recent advances and future directions. Heliyon. 2024;10(6):e31345.
4. Petersen ME, Khamas AB, Ostergaard LJ, Jorgensen NP, Meyer RL. Combination therapy delays antimicrobial resistance after adaptive laboratory evolution of *Staphylococcus aureus*. Antimicrob Agents Chemother. 2025;69(4):e01483-24.
5. Sharma A, Dhanda A, Naveen, Aggarwal NK, Singh A, Kumar P. Evaluation of phytochemical, antimicrobial, antioxidant, antidiabetic, antigenotoxic, antimutagenic and cytotoxic potential of leaf extracts of *Lantana camara*. Vegetos. 2025;38(3):1218-27.
6. Lourenco BJ, Massina CFO, Joao AA, Cuinica LG, Vintuar PA. Identification data of secondary metabolites and antibacterial action of leaf extract of *Lantana camara* L. on multidrug-resistant microorganisms. Data Brief. 2024;54:110338.
7. Ramírez J, Armijos C, Espinosa-Ortega N, Castillo LN, Vidari G. Ethnobotany, phytochemistry, and biological activity of extracts and non-volatile compounds from *Lantana camara* L. and semisynthetic derivatives--an updated review. Molecules. 2025;30(4):851.
8. Chaubey S, Rastogi N, Srivastava M. Exploring the medicinal potential of *Lantana camara*: a comprehensive

This open-access article is distributed under the terms of the Creative Commons Attribution Non Commercial 4.0 License (CC BY-NC 4.0).

review of phytochemicals and therapeutic application. Phytochem Rev. 2025;1-31.
9. Arra K, Pasupula R. Exploring the perspective of *Lantana camara* L. flowers for urolithiasis by in vitro and in vivo studies. Trop J Nat Prod Res. 2025;9(6):112-20.
10. Akyer SP, Karagur ER, Ata MT, Toprak EK, Donmez AC, Donmez BO. Verbascoside inhibits/repairs the damage of LPS-induced inflammation by regulating apoptosis, oxidative stress, and bone remodeling. Curr Issues Mol Biol. 2023;45(11):8755-66.
11. Shi C, Ma Y, Tian L, Li J, Qiao G, Liu C, et al. Verbascoside: an efficient and safe natural antibacterial adjuvant for preventing bacterial contamination of fresh meat. Molecules. 2022;27(15):4943.
12. Marčetić M, Bufan B, Drobac M, Antić Stanković J, Arsenović Ranin N, Milenković MT, et al. Multifaceted biological properties of verbascoside/actcoside: antimicrobial, cytotoxic, anti-inflammatory, and Immunomodulatory effects. Antibiotics. 2025;14(7):697.
13. Jayasinghe JMHM, Karunaratne DR. Invasive Alien Plant *Lantana Camara*—A Promising Antibacterial Agent for Combatting Multidrug Resistance. In: Transformative Applied Research in Computing, Engineering, Science and Technology, CRC Press; 2025:244-50.
14. Rajput P, Nahar KS, Rahman KM. Evaluation of antibiotic resistance mechanisms in gram-positive bacteria. Antibiotics. 2024;13(12):1197.
15. Xiao G, Li J, Sun Z. The combination of antibiotic and non-antibiotic compounds improves antibiotic efficacy against multidrug-resistant bacteria. Int J Mol Sci. 2023;24(20):15493.
16. Badawy T, Xu H, Li Y. Macroscopic spray characteristics of iso-octane, ethanol, gasoline and methanol from a multi-hole injector under flash boiling conditions. Fuel. 2022;307:121820.
17. Khalaf HA, Abbas IS, Tawfeeq AA, Mahdi MF. Determination, isolation, and identification of aucubin and verbascoside in the leaves of Iraqi *Plantago lanceolata* L. using different detecting methods. Int J Pharm Pharm Sci. 2018;11(2):74-80.
18. Frum Y, Viljoen AM, Van Heerden F. Verbascoside and luteolin-5-O-β-D-glucoside isolated from Halleria lucida L. exhibit antagonistic anti-oxidant properties in vitro. South Afr J Bot. 2007;73(4):583-7.
19. Sarkhail P, Nikan M, Sarkheil P, Gohari AR, Ajani Y, Hosseini R, et al. Quantification of verbascoside in medicinal species of Phlomis and their genetic relationships. DARU J Pharm Sci. 2014;22:1-9.
20. Aljamal MA, Hasan HM, Al Sonosy HA. Antibacterial activity investigation and antibiotic sensitive for different solvents (ethanol, propanol, DMSO and di ethel ether) extracts of seeds, leafs and stems of (*Laurus azorica* and *Avena sterilis*) plants. Int J Curr Microbiol App Sci. 2024;11:175-90.
21. Zapata A, Ramirez-Arcos S. A comparative study of McFarland turbidity standards and the Densimat photometer to determine bacterial cell density. Curr Microbiol. 2015;70:907-9.
22. Jena N, Vimala SB, Patra A, Sharma BP, Hossain E, Kumar S. Methods for ethnobotanical data collection, phytochemistry, antioxidant, anthelmintic, and antimicrobial activities for pharmacological evaluation of medicinal plants. J Biodivers Conserv. 2025;9(2):87-107.
23. Kubayi S, Makola RT, Dithebe K. Exploring the antimicrobial, antioxidant and extracellular enzymatic activities of culturable endophytic fungi isolated from the leaves of *Kirkia acuminata* Oliv. Microorganisms. 2025;13(3):692.
24. Matieta VY, Kuete V, Mbaveng AT. Anti-Klebsiella and antibiotic-potentiation activities of the methanol extracts of seven Cameroonian dietary plants against multidrug-resistant phenotypes over-expressing AcrAB-TolC efflux pumps. Invest Med Chem Pharmacol. 2023;6(1):73-85.
25. Aruguete D, Miller K, Wallace A, Blakney T, Muccio D, Pell R, et al. The effects of palladium coordination complex speciation and concentration upon the ubiquitous bacterial species *Pseudomonas aeruginosa*. Ecotoxicol Environ Saf. 2023;251:114512.
26. Soni V, Wang Z, Singh V. Editorial: Bacterial metabolomics approach towards antimicrobial assay and resistance. Front Microbiol. 2023;14:1222594.
27. Bellio P, Fagnani L, Nazzicone L, Celenza G. New and simplified method for drug combination studies by checkerboard assay. MethodsX. 2021;8:101543.
28. Abdulabbas SS, Ibrahim ZK, Muhammed HA, AL-Khazali NAY, Ahmed ST, Ai-Tuma AF, et al. Determination of fractional inhibitory concentration (FIC) index as a measure of synergy of antibiotics in *E. coli* O157: H7. Egypt J Hosp Med. 2022;89(2):7571-5.
29. Braga L, Leite AA, Xavier KG, Takahashi J, Bemquerer M, Chartone-Souza E, et al. Synergic interaction between pomegranate extract and antibiotics against *Staphylococcus aureus*. Can J Microbiol. 2005;51(7):541-7.
30. El-Banna AA, Darwish RS, Ghareeb DA, Yassin AM, Abdulmalek SA, Dawood HM. Metabolic profiling of Lantana camara L. using UPLC-MS/MS and revealing its inflammation-related targets using network pharmacology-based and molecular docking analyses. Sci Rep. 2022;12(1):14828.
31. Kato-Noguchi H, Kato M. Compounds involved in the invasive characteristics of Lantana camara. Molecules. 2025;30(2):411.
32. Saeed OM. Comparative evaluation of the phytochemical and morphological analysis and anti-inflammatory effect of *Lantana camara* on mice animal model. Iraqi J Vet Med. 2024;48(1):73-80.
33. Sharma M, Sharma SB. Anticancer activity of *Lantana Camara* hexane extract against brain carcinoma. Int J Chem Biol Sci. 2020;2(2):01-03.
34. Obukhova ES, Murzina SA. Mechanisms of the antimicrobial action of fatty acids: a review. Appl Biochem Microbiol. 2024;60(6):1035-43.
35. Joujou FM, Darra NE, Rajha HN, Sokhn ES, Alwan N. Evaluation of synergistic/antagonistic antibacterial

This open-access article is distributed under the terms of the Creative Commons Attribution Non Commercial 4.0 License (CC BY-NC 4.0).

activities of fatty oils from apricot, date, grape, and black seeds. Sci Rep. 2024;14(1):6532.
36. Moo CL, Yang SK, Osman MA, Yuswan MH, Loh JY, Lim WM, et al. Antibacterial activity and mode of action of β-caryophyllene on *Bacillus cereus*. Pol J Microbiol. 2020;69(1):49-54.
37. Martinez-Pabon MC, Ortega-Cuadros M. Thymol, menthol and eucalyptol as agents for microbiological control in the oral cavity: A scoping review. Rev Colomb Cienc Quim Farm. 2020;49 (1):44-69.
38. Silvan JM, Hurtado-Ribeira R, Martin D, Martinez-Rodriguez AJ. Antibacterial activity of fat from black soldier fly (Hermetia illucens) larvae against antibiotic resistant Campylobacter spp. strains. J Insects Food Feed. 2025;1 (aop):1-13.
39. Bardaji DK, Silva NB, Miranda RR, Martins CHG, Savka MA, Hudson AO. Unlocking the Potential of Brazilian Plant Terpenes to Combat Antimicrobial Resistance. ACS Bio Med Chem Au. 2025;5(3):365-78.
40. Hussein LM. Antibacterial activity of *Lantana camara* flower extracts against growth of pathogenic bacteria isolated from wounds and burns infections. Acad Sci J. 2023;1(3):45-55.
41. Singh H, Maithani D, Singh MC, Priyadarshi MB. Study of Antimicrobial activity of some selected weed species. Int J Sci Environ Technol. 2020;9(1):61-5.
42. Din SZU, Fazal MO, Ishitaque A, Ullah A. Antimicrobial activity of *Lantana camara* against *Pseudomonas aeruginosa*, *Serratia marcescens* and *Staphylococcus aureus* to develop ointment based therapy. Bull Biol All Sci Res. 2023;8:33-40.
43. Kumar R, Guleria N, Deeksha MG, Kumari N, Kumar R, Jha AK, et al. From an invasive weed to an insecticidal agent: Exploring the potential of *Lantana camara* in insect management strategies—A review. Int J Mol Sci. 2024;25(23):12788.
44. Schwartz B, Klamer K, Zimmerman J, Kale-Pradhan PB, Bhargava A. Multidrug resistant *Pseudomonas aeruginosa* in clinical settings: a review of resistance mechanisms and treatment strategies. Pathogens. 2024;13(11):975.
45. Behzadi P, Baráth Z, Gajdács M. It's not easy being green: a narrative review on the microbiology, virulence and therapeutic prospects of multidrug-resistant *Pseudomonas aeruginosa*. Antibiotics. 2021;10(1):42.
46. Yang Y, Wang X, Gao Y, Wang H, Niu X. Insight into the dual inhibitory mechanism of verbascoside targeting serine/threonine phosphatase Stp1 against *Staphylococcus aureus*. Eur J Pharm Sci. 2021;157:105628.
47. Choudhury A. Potential role of bioactive phytochemicals in combination *therapies* against antimicrobial activity. J Pharmacopuncture. 2022;25(2):79-85.

This open-access article is distributed under the terms of the Creative Commons Attribution Non Commercial 4.0 License (CC BY-NC 4.0).