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Comparative Assessment of Antibacterial, Antifungal, Antimalarial, and Antioxidant Activity of Aqueous Methanolic Extracts of Common Culinary, Aromatic, and Traditional Medicinal Plants

Saleh M. Matar[1]
[1]Chemical Engineering Department, Faculty of Engineering and Computer Science, Jazan University, Jazan, 45142, Saudi Arabia.
Corresponding author: Saleh M. Matar (e-mail: sel-saidmatar@jazanu.edu.sa).

ABSTRACT Medicinal plants are fundamental sources of bioactive compounds that possess significant antimicrobial, antioxidant, and anti-inflammatory properties. They are commonly utilized in culinary, aromatic, and traditional medicine applications. This study presents a comparative analysis of the aqueous methanolic extracts of nine conventional plants—*Cinnamomum verum*, *Cuminum cyminum*, *Curcuma longa*, *Syzygium aromaticum*, *Cassia angustifolia*, *Elettaria cardamomum*, *Zingiber officinale*, *Foeniculum vulgare*, and *Ocimum basilicum*—focusing on their antimicrobial and antioxidant effects. The extracts were evaluated against various pathogenic strains, including Gram-positive bacteria, Gram-negative bacteria, fungi, and *Plasmodium chabaudi*. *Elettaria cardamomum* exhibited the strongest antibacterial activity, followed closely by *Cassia angustifolia*, *Syzygium aromaticum*, and *Zingiber officinale*, while *Cinnamomum verum* exhibited no antibacterial activity. *Curcuma longa*, *Cassia angustifolia*, and *Elettaria cardamomum* demonstrated notable antifungal properties. *Elettaria cardamomum* and *Cassia angustifolia* achieved high antimalarial activity against *Plasmodium chabaudi*, while *Foeniculum vulgare* and *Ocimum basilicum* exhibited moderate inhibition. Furthermore, the extracts displayed varying tendencies to scavenge DPPH and hydroxyl radicals, with *Cinnamomum verum* being the most effective in radical scavenging. The observed differences in biological activity are attributed to the unique phytochemical profiles of the plants, suggesting their potential as natural alternatives for managing infections and oxidative stress. Our findings highlight the significance of exploring medicinal plants for sustainable healthcare solutions, particularly in the context of rising antimicrobial resistance, while suggesting that further research into their synergistic effects and broader applications in food and health could enhance their therapeutic potential.
The study highlights the significant antimicrobial activity of various plant extracts, with *Elettaria cardamomum* and *Cassia angustifolia* showing strong antibacterial and antifungal properties, particularly against Gram-positive bacteria and certain fungi. These effects are attributed to bioactive compounds that disrupt microbial cell structures and induce oxidative stress.
Additionally, the plants demonstrated varying antioxidant activities, with *Cinnamomum verum* exhibiting strong radical scavenging capabilities, while *Curcuma longa* showed the weakest effects. The differences in antioxidant potential are linked to the unique phytochemical profiles of each plant, which include flavonoids, phenolics, and essential oils.

INDEX TERMS Antioxidants, Antimicrobial Activity, Traditional Medicine, Phytochemicals, Medicinal Plants.

I. INTRODUCTION

Commonly used traditional plants offer a wealth of therapeutic applications in cultural practices [1]. They are rich in bioactive compounds that exhibit antioxidant, anti-inflammatory, and antimicrobial properties, which make them effective for managing various diseases and promoting health [2, 3]. These plants serve as natural alternatives to synthetic drugs, with fewer side effects, and are readily available in rural areas. Moreover, their use can lead to synergistic effects and contribute to the discovery of new pharmaceuticals, as most advanced medicines are derived from plant sources [4, 5]. Antimicrobials such as antibacterial, antiviral, antifungal, and antiparasitic drugs can be used to prevent and treat infections, assisting in the prevention of the spread of infectious diseases [6]. The emergence of antimicrobial resistance emphasizes the importance of finding advanced antimicrobial methods and suggests the use of plant-derived natural products as potential solutions.

On the other hand, free radicals are generated by the normal function of tissues in a biological system. They are involved in the control of signal transduction, gene expression, and receptor activation. However, an excess of free radicals, such as superoxide, hydrogen peroxide, hydroxyl, and nitrogen radicals, is toxic and a primary cause of oxidative stress. Oxidative stress leads to numerous diseases, including age-related disorders, neurodegenerative diseases, atherosclerosis, infections, cancer, and diabetes [7]. Antioxidants and antimicrobial agents play crucial roles in health and disease prevention. They neutralize free radicals, which can damage cells and lead to chronic diseases. By combating oxidative damage, antioxidants support overall cellular health and may enhance longevity.

Recently, interest in plants has greatly increased; therefore, most regulatory guidelines and pharmacopeia suggest a chemical analysis of plant materials, including fractions and extracts, to find natural antioxidants for human diseases linked to oxidative stress. Echinacea and goldenseal are used for immune-boosting and antibacterial effects, respectively, while ginger and turmeric are employed for their anti-inflammatory properties. Adaptogens like ashwagandha and rhodiola serve traditional applications. Many phytochemicals play a significant role in neutralizing free radicals, quenching single and triple oxygen, or decomposing peroxides. An inverse relationship has been reported between lower incidence and mortality rates for many human diseases and increased antioxidant status [8]. Plants contain free radical scavengers, such as polyphenols, flavonoids, and phenolic compounds, which inhibit the adverse effects of oxidative stress [9, 10].

Plants such as *Cinnamomum verum* (cinnamon), *Cuminum cyminum* (cumin), *Curcuma longa* (turmeric), *Syzygium aromaticum* (clove), *Cassia angustifolia* (senna), *Elettaria cardamomum* (cardamom), *Zingiber officinale* (ginger), *Foeniculum vulgare* (fennel), and *Ocimum basilicum* (basil) are commonly utilized in many countries worldwide. The selected plants have been used in traditional medicine due to their potent healing properties and contemporary holistic approaches. Various clinical studies have assessed their role in treating many diseases, such as digestive disorders, respiratory issues, and skin conditions. They possess diverse medicinal properties, culinary applications, and ecological significance and are studied for their health benefits, including anti-inflammatory, antimicrobial, and digestive properties, as well as their potential in managing chronic diseases and improving food preservation. Their rich phytochemical profiles make them beneficial for discovering new therapeutic applications. Hence, this study aims to evaluate the antimicrobial and antioxidant properties of aqueous methanolic extracts of conventional plants, including *Cinnamomum verum*, *Cuminum cyminum*, *Curcuma longa*, *Syzygium aromaticum*, *Cassia angustifolia*, *Elettaria cardamomum*, *Zingiber officinale*, *Foeniculum vulgare*, and *Ocimum basilicum*. Additionally, it aims to provide recommendations for incorporating these extracts into food, nutraceuticals, and herbal medicine, ultimately enhancing the understanding of their health benefits and potential applications in disease prevention and treatment. The study paves the way for alternatives to conventional therapy to address the growing challenge of antimicrobial resistance.

II. Materials and Methods

Selection of Plants

The dried plant materials were obtained from a local market in Saudi Arabia. The plant materials consist of *Cinnamomum verum* (cinnamon), *Cuminum cyminum* (cumin), *Curcuma longa* (turmeric), *Syzygium aromaticum* (clove), *Cassia angustifolia* (senna), *Elettaria cardamomum* (cardamom), *Zingiber officinale* (ginger), *Foeniculum vulgare* (fennel), and *Ocimum basilicum*. They are widely used because of their versatile applications, as depicted in Table 1, which shows the scientific names, family names, and traditional uses for these plants.

Table 1 List of plant materials

No	Plant name	The scientific name	Family name	Traditional uses
1	Cinnamon	*Cinnamomum verum*	Lauraceae	Aromatic
2	Cumin	*Cuminum cyminum*	Apiaceae	Culinary
3	Turmeric	*Curcuma longa*	Zingiberaceae	Culinary/Aromatic
4	Clove	*Syzygium aromaticum*	Myrtaceae	Aromatic
5	Senna	*Cassia Angustifolia*	Caesalpinaceae	Medicinal

6	Cardamomum	*Elettaria cardamomum*	Zingiberaceae	Culinary/Aromatic
7	Ginger	*Zingiber officinale*	Zingiberaceae	Culinary/Aromatic
8	Sweet Fennel	*Foeniculum vulgare*	Carrot (Apiaceae)	Culinary/Aromatic
9	Ocimum	*Ocimum basilicum*	Lamiaceae	Culinary/Aromatic

Preparation of Extracts

About 20 g of dried plant materials were soaked in 50 ml of 80% (v/v) aqueous methanol at room temperature for 3 days in a dark place. The soaked material was stirred every 18 h using a sterilized glass rod. It was then filtered and centrifuged for 20 mins to get the clear supernatant, which was evaporated to dryness for 24 h at room temperature. The remaining extract was freeze-dried and stored at -20° C.

Antimicrobial Activity Assays

Inoculum preparation

Trichophyton rubrum ATCC 28189, *Candida albicans* ATCC 10231, and *Candida tropicalis ATCC* 13803 were cultivated in compliance with Clinical Laboratory and Standard Institute document M27-A3 [11]. Fungal strains were cultivated for 48 h on Sabouraud-dextrose (SD, Acumedia, USA) agar, and the isolated colonies were subsequently suspended in a 0.85% NaCl saline solution (Synth, Brazil). The density of the resultant suspension was calibrated to 106 colony-forming units (CFU)/ml, equivalent to the 0.5 McFarland standard. Subsequently, 1×10^3 CFU/ml of SD broth (Acumedia, USA) was utilized to dilute the fungal solution. Suspensions of Gram-negative and Gram-positive bacteria, such as *Bacillus subtilis* ATCC 6633, *Staphylococcus aureus* ATCC 24213, *Enterococcus faecalis* ATCC 51299, *Klebsiella pneumonia* ATCC 700603, *Escherichia coli* ATCC 47076, and *Pseudomonas aeruginosa* ATCC 27853, were cultured on Petri dishes containing nutrient broth (NB, HiMedia, India) for 24 h at 37°C. After the incubation period, each strain was diluted to a final concentration of 10^5 cells/ml utilizing sterile Ringer's solution. The Department of Biological Sciences at King Faisal University in Saudi Arabia kindly provided all test strains.

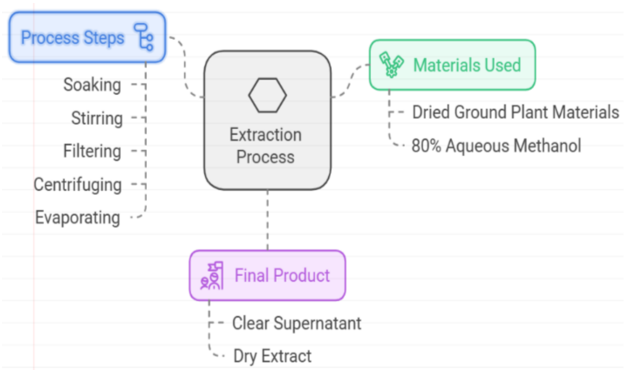

Figure 1 Preparation of extracts

Antimicrobial test

The agar well diffusion method, as detailed by [12], was used to conduct the experiment. Using a non-toxic swab, a fresh microbial culture containing 100 microliters (10^6 CFU/ml) was spread on a Muller Hilton agar plate. Using a sterile cork-borer (6 mm), four 6-mm diameter wells were created in the agar medium, and 100 µl (500 mg/ml) of each plant extract was added to each well using a micropipette while maintaining aseptic conditions. DMSO was employed as the control group. The plates were allowed to stand for one hour to allow the extract to pre-diffuse into the medium. The plates were then incubated for 24 to 48 h at 37 ± 2°C in an upright position under aerobic conditions. The inhibition zone (mm) was measured to assess the antimicrobial activity.

Minimum inhibitory concentration

The broth microdilution method was used to determine the minimum inhibitory concentration (MIC) [13, 14]. MIC values were utilized to estimate the antibacterial activity of plant extracts against pathogenic bacterial and fungal strains. In summary, the refined substance was dissolved in DMSO (1 mg/ml, Sigma-Aldrich, USA) in a 96-well plate and diluted twice to achieve concentrations of 1000–0.5 µg/ml. After injecting 100 µl of each pathogen suspension and 100 µl of the tested plant extract into each well, the combination was incubated at 37°C for 48 h. At the conclusion of the incubation period, the MIC values—the lowest concentrations of the drug that prevent microbial growth—were noted. Amphotericin B® and streptomycin (Sigma Chemical Co., St. Louis, MO, USA) were added as positive controls, and experiments were run in parallel with DMSO serving as the solvent control. Every test was performed in triplicate.

***In vitro* antiplasmodial activity**

An approach from [15] was slightly adjusted to evaluate the antimalarial activity. To summarize, 1.0 mg of each extract was diluted and dissolved in DMSO to create a (5.0 mg/mL) stock solution, which was then kept at -20°C until needed. The Department of Biological Sciences at King Faisal University in Saudi Arabia provided 200 µl of *Plasmodium chabaudi*, a malarial parasite. The parasite was grown in a 24-well culture plate at different dosages (0.01–10 mg/ml) for 48 h at 37°C. Dihydroartemisinin, a typical antimalarial medication, was utilized as a positive control in this method. Negative controls were created with 1% DMSO. Inhibition of the parasite was quantified as a percentage of the growth of the untreated (negative) control. Every investigation was conducted in triplicate.

Assay of Antioxidant Activity

Scavenging of DPPH Radical Method

DPPH radical is frequently utilized to study the free radical scavenging ability of natural candidates. It includes measuring the scavenging properties of specific substances against a stable radical. The scavenging activity was assessed as follows: 0.5 mL of the extracts (0.1–0.5 mg/mL) were mixed with 3 mL of a 0.1 mM solution of DPPH in methanol and left in a dark place for about 30 mins. The absorbance was recorded at 517 nm using a UV-Vis spectrophotometer. Blank samples were used to control the experiment, containing (DPPH and methanol instead of the sample. Vitamin C was used as a typical antioxidant. The activity of the extracts was expressed as a percentage of inhibition (% inhibition) of each free radical scavenging activity (Sanchez-Moreno et al. (1998) [16].

Hydroxyl Radical Scavenging Method

This method is estimated by an advanced Fenton-type reaction. Equal amounts of the investigated candidates were incubated with 9 mM FeSO4, 9 mM salicylic acid-ethanol, and 9 mM H_2O_2 at 37°C for one h, and absorbance was recorded at 510 nm. Distilled water was used as a control, and ascorbic acid served as a positive control. Finally, the hydroxyl radical scavenging activity was determined [17].

Statistical Analysis

The data represent the mean of three replicates ± standard error mean (SEM) using SPSS version 20.0 (Statistical Package for the Social Sciences, Inc., Chicago, IL, United States).

III. Results

Antimicrobial Activity

The antibacterial activity of the investigated plant aqueous methanolic extracts against six pathogenic bacteria is shown in Table 2. Three Gram-negative bacteria (*Pseudomonas aeruginosa*, *Escherichia coli*, and *Klebsiella pneumonia)* and three Gram-positive bacteria *(Staphylococcus aureus*, *Bacillus subtilis*, and *Enterococcus faecalis*) were employed as pathogenic bacteria. The antibacterial activity was assessed by measuring the zone of inhibition in millimeters (mm) after incubation of each bacterium with each plant extract. Among the tested extracts, *Elettaria cardamomum* exhibited the highest inhibition, revealing strong antibacterial properties, followed by *Cassia angustifolia*, *Syzygium aromaticum*, and *Zingiber officinale*, which exhibited notable inhibition. In contrast, *Ocimum basilicum* demonstrated moderate effectiveness. *Foeniculum vulgare* and *Cuminum cyminum* showed limited activity. *Curcuma longa* and *Cinnamomum verum* exhibited weaker antibacterial effects. Overall, the findings highlighted that *Elettaria cardamomum* and *Cassia angustifolia* are potent antibacterial agents.

Table 2 Antibacterial activity of investigated plant extracts against pathogenic bacteria

	Zone of inhibition (mm) of each Pathogenic bacterium					
	Pseudomonas aeruginosa	*Escherichia coli*	*Klebsiella pneumonia*	*Staphylococcus aureus*	*Bacillus subtilis*	*Enterococcus faecalis*
Cinnamomum verum	5.7±0.47	3.5±0.40	3.9±0.28	8.4±0.30	7.9±0.15	10.2±0.27
Cuminum cyminum	2.1 ± 0.41	na	3.7±0.88	6.1±0.66	13.5±0.32	11.9±0.65
Curcuma longa	na	na	na	8.9±0.22	4.2±0.45	5.8±0.81
Syzygium aromaticum	18.6±0.11	19.2±0.22	17.8±0.16	22.8±0.56	22.9±0.62	13.2±0.21
Cassia Angustifolia	14.2±0.5	19.8±0.20	11.6±0.70	29.7±0.28	24.8±0.15	28.1±0.25
Elettaria cardamomum	23.2±0.11	30.4±0.11	24.2±0.62	29.7±0.41	20.9±0.22	24.3±0.37
Zingiber officinale	20.3±0.52	15.5±0.76	13.6±0.14	14.4±0.27	21.1±0.58	25.9±0.16
Foeniculum vulgare	9.7±0.57	13.4±0.71	11.2±0.42	9.8±0.34	8.3±0.31	14.2±0.23
Ocimum basilicum	20.1±0.15	11.2±0.18	10.2±0.22	na	na	na
Streptomycin	35.3±0.85	28.8±0.48	30.0±0.87	30.2±0.77	33.9±0.49	32.6±0.33
DMSO	-	-	-	-	-	-

Growth Inhibition Zone (mm) ± SEM; na: not active
Amphotericin B as antibacterial positive control.
1% dimethyl sulfoxide (DMSO); negative control.

The antifungal action of the investigated plant aqueous methanolic extracts was assessed using three pathogenic fungal strains: *Candida tropicalis*, *Candida albicans*, and *Trichophyton rubrum*. The antifungal activity was measured by the zone of inhibition (mm), as shown in Table 3. Notably, *Cinnamomum verum* showed no activity against any of the tested fungi. In contrast, *Cuminum cyminum* demonstrated minimal effectiveness, with inhibition zones of 3.0 ± 0.92 mm against *Candida tropicalis* and 5.9 ± 0.50 mm against *Candida albicans*. *Syzygium aromaticum* showed slightly lower inhibition with 8.7 ± 0.76 mm for *Candida tropicalis* and 12.7 ± 0.52 mm for *Candida albicans*. *Curcuma longa* exhibited strong antifungal activity, particularly against *Candida tropicalis* (23.7 ± 0.22 mm) and *Trichophyton rubrum* (21.8 ± 0.96 mm). Both *Cassia angustifolia* and *Elettaria cardamomum* displayed promising antifungal properties, with *Cassia angustifolia* achieving the highest inhibition against *Candida tropicalis* (29.1 ± 0.79 mm). *Elettaria cardamomum* and *Zingiber officinale* showed the highest overall inhibition. In contrast, *Foeniculum vulgare* and *Ocimum basilicum* exhibited limited antifungal activity, with the lowest inhibition zones observed. Overall, the results indicated that several plant extracts, particularly *Cassia angustifolia* and *Elettaria cardamomum*, exhibited significant antifungal effects, highlighting their potential for therapeutic applications.

Table 3 Antifungal activity of investigated plant extracts against fungal pathogenic strains

	Zone of inhibition (mm) of each pathogenic fungus		
	Candida tropicalis	*Candida albicans*	*Trichophyton rubrum*
Cinnamomum verum	na	na	Na
Cuminum cyminum	3.0±0.92	5.9±0.50	Na
Curcuma longa	23.7 0.22	14.2±0.70	21.8±0.96
Syzygium aromaticum	8.7.3±0.76	12.7±0.52	18.4±0.21
Cassia Angustifolia	29.1±0.79	27.6±0.55	25.4±0.40
Elettaria cardamomum	28.2±0.88	29.9±0.67	31.1±0.41
Zingiber officinale	30.6±0.26	31.5±0.26	20.7±0.36
Foeniculum vulgare	12.4±0.37	13.1±0.46	6.4±0.25
Ocimum basilicum	3.8±0.72	9.4±0.29	3.5±0.12
Amphotericin B	22.2±0.97	24.8±0.40	31.1±0.80
DMSO	-	-	-

Growth Inhibition Zone (mm) ± SEM; na: not active
Streptomycin as a positive antifungal control.
1% dimethyl sulfoxide (DMSO); negative control.

The MIC values (µg/ml) of the investigated plant extracts against specific bacterial and fungal pathogens were measured and displayed in *Table 4*. It was noted that aqueous methanolic plant extracts exhibited significant variability in effectiveness. For fungal pathogens, *Candida albicans* exhibited sensitivity at 31.25 µg/ml for certain extracts, while others require higher concentrations. *Syzygium aromaticum*, *Cassia angustifolia*, *Elettaria cardamomum*, and *Zingiber officinale* demonstrated strong activity with MIC values among the other extracts, ranging from 500 to 31.25 µg/ml. In contrast, Amphotericin B, the positive antifungal control, had an MIC value of 0.5 µg/ml. Other extracts showed moderate to weak activity with MIC values ranging from 500 to >1000 µg/ml. Overall, the findings suggest the potential for certain plant extracts as alternative antimicrobial agents, warranting further investigation.

Table 4 Minimum inhibitory concentration (MIC) values (µg/ml) of some plant extracts against bacterial and fungal pathogenic strains

	Pathogen	Plant extracts (µg/ml)								
		Cinnamomum verum	*Cuminum cyminum*	*Curcuma longa*	*Syzygium aromaticum*	*Cassia Angustifolia*	*Elettaria cardamomum*	*Zingiber officinale*	*Foeniculum vulgare*	*Ocimum basilicum*
Bacteria	*Pseudomonas aeruginosa*	500	500	>1000	125	250	250	125	500	125
	Escherichia coli	500	>1000	>1000	125	250	125	250	250	500
	Klebsiella pneumonia	>1000	125	>1000	125	250	250	125	500	500
	Staphylococcus aureus	>1000	500	500	62.5	31.25	62.5	62.5	500	>1000
	Bacillus subtilis	500	125	500	62.5	31.25	250	250	500	>1000
	Enterococcus faecalis	>1000	250	250	250	31.25	125	250	250	>1000
Fungi	*Candida tropicalis*	>1000	250	125	500	31.25	31.25	31.25	500	250
	Candida albicans	>1000	250	125	500	62.5	31.25	31.25	251	250
	Trichophyton rubrum	>1000	>1000	250	125	125	62.5	31.25	250	>1000
	DMSO	–	–	–	–	–	–	–	–	–

The antimalarial activity of nine aqueous methanol plant extracts against *Plasmodium chabaudi* after a 48-hour incubation period is presented in Table 5. The activity is measured as the percentage of inhibition at different concentrations (0.01–10 mg/ml) of each plant extract. At the lowest concentration of 0.01 mg/ml, *Elettaria cardamomum* demonstrated the highest inhibition at 20.7 ± 0.8%, while *Cuminum cyminum* showed the least effect at 2.3 ± 1.6%. As the concentration increased to 0.1 mg/ml, *Cassia angustifolia* exhibited a notable rise in inhibition to 43.9 ± 2.6%, positioning it among the more effective extracts, whereas *Cuminum cyminum* remained low at 3.8 ± 3.4%. At a concentration of 1.0 mg/ml, *Cassia angustifolia* again led with 72.8 ± 4.7% inhibition, while other extracts like *Elettaria cardamomum* and *Zingiber officinale* also showed significant activity (60.7 ± 2.1% and 59.3 ± 6.8%, respectively). The highest concentration of 10 mg/ml revealed that *Elettaria cardamomum* achieved a potent 91.3 ± 3.2% inhibition, closely followed by *Cassia angustifolia* at 89.9 ± 3.2%. In comparison, the synthetic antimalarial drug dihydroartemisinin exhibited potent effects, with inhibition rates exceeding 97% across all concentrations tested. The negative control group, which received no mutagen, showed no inhibition. Overall, the results implied that *Foeniculum vulgare* and *Ocimum basilicum* exhibited moderate inhibition. Moreover, *Cassia angustifolia* and *Elettaria cardamomum* possessed significant antimalarial properties, highlighting their potential as alternative therapeutic agents.

Table 5 *In vitro* antimalarial activity of methanolic plant extracts against *P. chabaudi* after 48 h incubation period

Conc. (mg/ml)	% of inhibition									
	Cinnamomum verum	*Cuminum cyminum*	*Curcuma longa*	*Syzygium aromaticum*	*Cassia Angustifolia*	*Elettaria cardamomum*	*Zingiber officinale*	*Foeniculum vulgare*	*Ocimum basilicum*	dihydroartemisinin
0.01	9.97±0.7	2.3±1.6	8.9±5.4	1.1±2.1	15.7±4.1	20.7±0.8	12.3±5.4	10.5±2.6	13.9±0.4	95.3±2.5

0.1	11.94±1.3	3.8±3.4	10.1±6.8	1.8±0.8	43.9±2.6	25.8±2.5	28.7±6.2	16.8±4.8	14.5±1.8	97.6±3.2
1.0	14.5±1.1	6.9±1.5	10.9±4.2	2.3±1.8	72.8±4.7	60.7±2.1	59.3±6.8	24.6±3.7	50.8±1.2	97.9±1.8
10	15.2±2.2	28.7±0.9	12.5±4.2	2.5±3.3	89.9±3.2	91.3±3.2	88.7±4.3	41.9±1.9	60.2±3.7	98.1±2.7

Antioxidant activity

Antioxidant activity (DPPH free radical scavenging activity) of methanolic extracts:

The principle is that when DPPH radicals are incubated with substances that have antioxidant properties, DPPH is reduced from its characteristic violet to a yellow-colored radical, which is measured calorimetrically. The DPPH radical scavenging activity of various plant extracts is denoted in Figure 1. All the extracts displayed distinct levels of DPPH radical scavenging activity. The value of antioxidant activity with a percentage of inhibition for *Cinnamomum verum*, *Cuminum cyminum*, *Curcuma longa*, *Syzygium aromaticum*, *Cassia angustifolia*, *Elettaria cardamomum*, and *Zingiber officinale* was found to be 55.4%, 89.93%, 15.95%, 88.12%, 71.71%, 16.74%, 70.9%, 89.59%, and 90.15%, respectively. *Ocimum basilicum*, *Cuminum cyminum*, *Syzygium aromaticum*, and *Foeniculum vulgare* exhibited robust DPPH radical scavenging activity compared to other extracts, while *Curcuma longa* exhibited the weakest DPPH radical scavenging activity. The radical scavenging activity of the plant extracts was in the following order: *Ocimum basilicum* > *Cuminum cyminum* > *Foeniculum vulgare* > *Syzygium aromaticum* > *Cassia Angustifolia* > *Zingiber officinale* > *Cinnamomum verum* > *Elettaria cardamomum* > *Curcuma longa.*

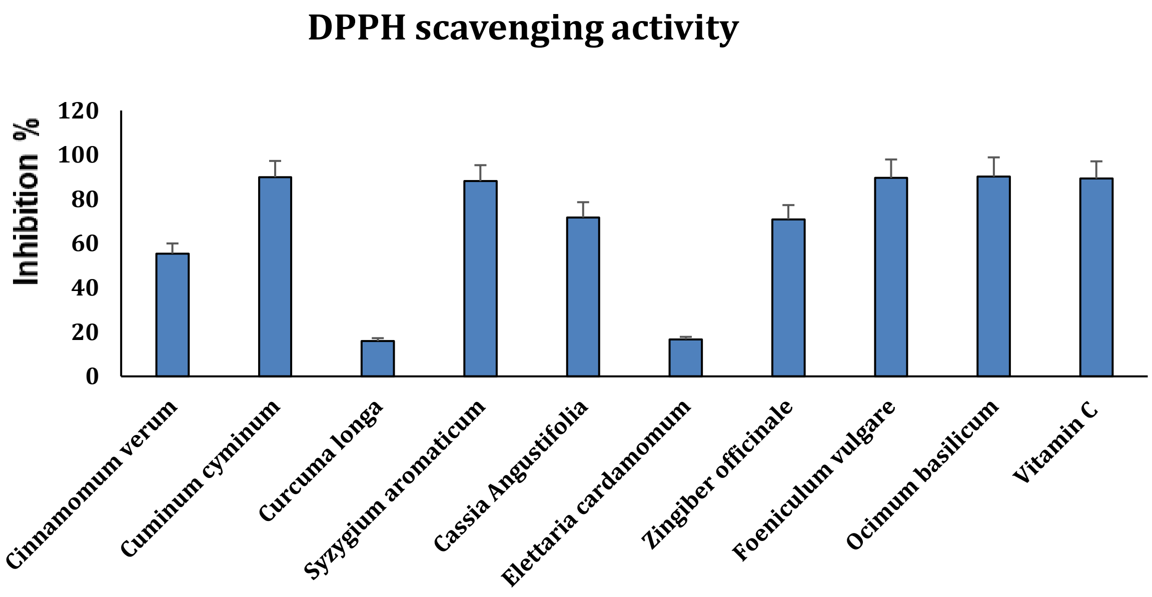

Figure 2 DPPH scavenging activity for the different plant extracts.

Antioxidant activity (Hydroxyl radical scavenging activity) of methanolic extracts

Hydroxyl radicals can easily penetrate cell membranes to interact with many biomolecules, inducing tissue injury or cellular death. Therefore, eliminating hydroxyl radicals is critical for protecting living systems [18, 19]. The plant extracts' hydroxyl radical scavenging activity of *Cinnamomum verum*, *Cuminum cyminum*, *Curcuma longa*, *Syzygium aromaticum*, *Cassia angustifolia*, *Elettaria cardamomum*, *Zingiber officinale*, *Foeniculum vulgare*, and *Ocimum basilicum* was found to be 86.1%, 5.4%, 9.55%, 19.2%, 8.3%, 31.1%, 30.8%, 16.3%, and 1.5%, respectively, as shown in Figure 3. The highest hydroxyl radical scavenging capabilities were recorded for the extract of *Cinnamomum verum*. The extracts of *Cuminum cyminum*, *Curcuma longa*, *Syzygium aromaticum*, *Cassia angustifolia*, *Elettaria cardamomum*, *Zingiber officinale*, *Foeniculum vulgare*, and *Ocimum basilicum* showed moderate to weak hydroxyl radical scavenging activity, with the extract of *Ocimum* basilicum showing the lowest scavenging activity.

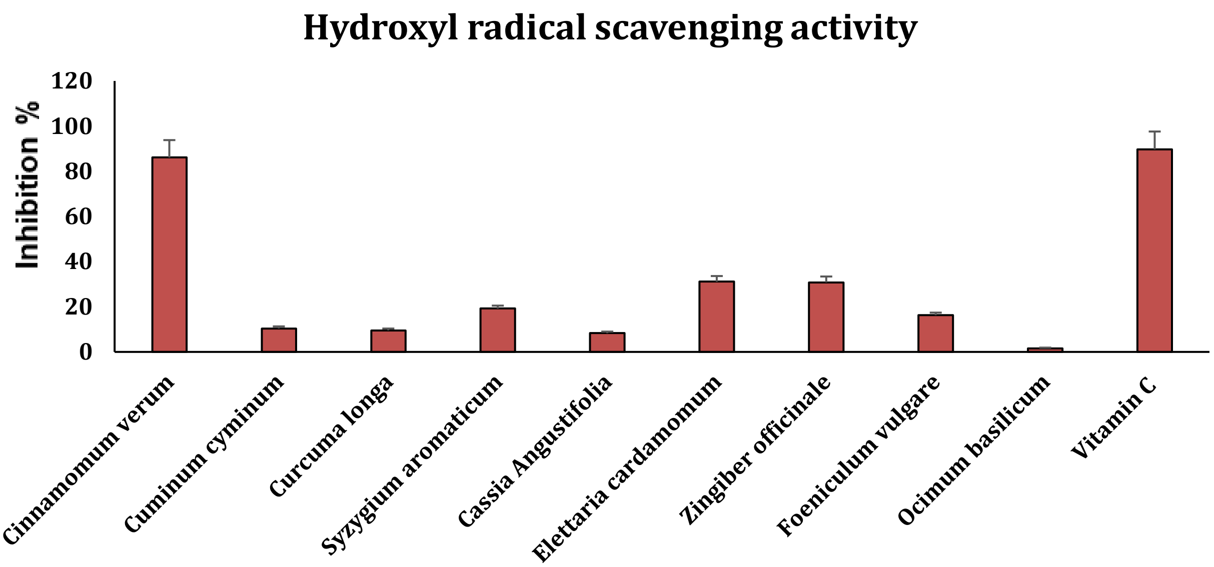

Figure 3 Hydroxyl radical scavenging activity for the different plant extracts.

IV. Discussion

Medicinal plants are crucial sources of bioactive and pharmaceutically important compounds that have antimicrobial, antioxidant, anti-inflammatory, and various other biological and medicinal applications. Some of these plants are commonly used in everyday life as medicinal, culinary, and aromatic agents. In this study, the aqueous methanolic extract of conventional plants, including *Cinnamomum verum*, *Cuminum cyminum*, *Curcuma longa*, *Syzygium aromaticum*, *Cassia angustifolia*, *Elettaria cardamomum*, *Zingiber officinale*, *Foeniculum vulgare*, and *Ocimum basilicum*, has been comparatively investigated for its antimicrobial and antioxidant properties.

Plants like *Cinnamomum verum* (cinnamon), *Cuminum cyminum* (cumin), *Curcuma longa* (turmeric), *Syzygium aromaticum* (clove), *Cassia angustifolia* (senna), *Elettaria cardamomum* (cardamom), *Zingiber officinale* (ginger), *Foeniculum vulgare* (fennel), and *Ocimum basilicum* (basil) are commonly utilized in many countries worldwide due to their diverse medicinal properties, culinary applications, and ecological significance. They are studied for their health benefits, including anti-inflammatory, antimicrobial, and digestive properties, as well as their potential in managing chronic diseases and improving food preservation. Their rich phytochemical profiles make them valuable for exploring new therapeutic applications and enhancing agricultural practices. This was in agreement with various studies that explored the biological applications of these plants [2, 3]. This is the first comparative analysis of the investigated plants.

Table 6 Key chemical compounds of investigated medicinal plants

No.	Plant	Key Chemical Compounds	References
1	*Cinnamomum verum*	Cinnamaldehyde, Eugenol, Coumarin, Myrcene and p-Cymene	[20-25]
2	*Cuminum cyminum*	Cuminaldehyde, Limonene, Thymol	[26-33]
3	*Curcuma longa*	Curcumin, Demethoxycurcumin, Bisdemethoxycurcumin	[34-42]
4	*Syzygium aromaticum*	Eugenol, Beta-caryophyllene, Acetyl eugenol	[43-52]
5	*Cassia angustifolia*	Sennosides (A and B), Anthraquinones	[53-62]
6	*Elettaria cardamomum*	1,8-Cineole, Limonene, Alpha-terpineol	[63-72]
7	*Zingiber officinale*	Gingerol, Shogaol, Zingerone	[33, 73-78]
8	*Foeniculum vulgare*	Anethole, Fenchone, Estragole	[79-87]
9	*Ocimum basilicum*	Eugenol, Linalool, Rosmarinic acid	[88-96]

The complex nature and composition of these plants indicate their potential for diverse applications based on their chemical profiles. The antibacterial, antifungal, and antimalarial activities of various plant aqueous methanolic extracts were evaluated against pathogenic strains. Three Gram-negative bacteria (*Pseudomonas aeruginosa*, *Escherichia coli*, and *Klebsiella pneumonia)* and three Gram-positive bacteria *(Staphylococcus aureus*, *Bacillus subtilis*, and *Enterococcus faecalis*) were employed as pathogenic bacteria. *Elettaria cardamomum* emerged as the most effective antibacterial agent, followed closely by *Cassia angustifolia*, *Syzygium aromaticum*, and *Zingiber officinale*, while *Cinnamomum verum* showed no antibacterial activity. Gram-positive bacteria were more susceptible to the methanolic extracts of *Elettaria cardamomum*, which could be related to the presence of 1,8-Cineole, as suggested by previous studies [97–99], and Limonene [100, 101], as well as other active components such as Alpha-terpineol [102, 103]. Furthermore, *Syzygium aromaticum contains* Eugenol [104, 105] and Beta-caryophyllene [106], which have been reported in other studies to exhibit antimicrobial activity. The antifungal assessments of the investigated plant aqueous methanolic extracts against three pathogenic fungal strains—*Candida tropicalis*, *Candida albicans*, and *Trichophyton rubrum*—were measured by the zone of inhibition. *Curcuma longa* exhibited strong inhibition, particularly against *Candida tropicalis*, which is in agreement with previous studies showing the potential antimicrobial activities of its aqueous extract [107, 108]. Both *Cassia angustifolia* and *Elettaria cardamomum* demonstrated significant antifungal properties [60, 109, 110]. In contrast, *Foeniculum vulgare* and *Ocimum basilicum* showed limited antifungal activity, with the lowest inhibition zones observed. In the evaluation of antimalarial activity against *Plasmodium chabaudi*, Dihydroartemisinin is a drug used to treat malaria effectively through the production of free radicals that damage the essential biomolecules needed for the growth of *Plasmodium chabaudi*. The plant extracts exhibited antimalarial activities in different potencies. *Foeniculum vulgare* and *Ocimum basilicum* exhibited moderate inhibition, while *Elettaria cardamomum* and *Cassia angustifolia* achieved high inhibition rates. Specific compounds may target the metabolic pathways of Plasmodium species [111–113]. Furthermore, these extracts may enhance the host's immune response, aiding in infection clearance. Overall, the results suggest that *Cassia angustifolia* and *Elettaria cardamomum* possess considerable potential as therapeutic agents against bacterial, fungal, and malaria infections. This could be attributed to the bioactive compounds that disrupt microbial cell walls [114], inhibit protein and nucleic acid synthesis [115, 116], and alter cell membrane permeability, leading to cell lysis [117, 118]. Additionally, they may generate reactive oxygen species (ROS) that induce oxidative stress, damaging cellular components [119]. The synergistic effects of multiple phytochemicals can enhance antimicrobial efficacy [120]. Collectively, these mechanisms highlight the therapeutic potential of plant extracts as natural alternatives to conventional treatments, especially in light of increasing drug resistance. The promising antibacterial, antifungal, and antimalarial activities of these plant extracts underscore their potential as therapeutic agents in combating infectious diseases. The implications of these findings suggest a future where natural plant extracts could play a vital role in public health strategies, particularly in the context of rising antimicrobial resistance and the need for sustainable healthcare solutions.

Furthermore, the study examined the ability of various plant extracts to neutralize DPPH and hydroxyl radicals. The extracts demonstrated varying levels of DPPH and hydroxyl radical scavenging activity, with notable percentages of inhibition for *Cinnamomum verum and Cuminum cyminum*, while *Curcuma longa* showed the weakest effect. Additionally, the extracts' ability to scavenge hydroxyl radicals varied, with *Cinnamomum verum* showing the strongest activity, whereas *Ocimum basilicum* had the lowest. The variation in antioxidant actions of the plant extracts can be related to their unique phytochemical compositions, which include varying levels of flavonoids, phenolics, and essential oils that affect their ability to neutralize radicals. Each plant has developed different mechanisms for oxidative stress modification. Additionally, some extracts may contain synergistic compounds that enhance overall effectiveness. The relationship between antioxidant mechanisms and antimicrobial efficacy needs further exploration to understand their combined effects better.

V. Conclusion

The study identified significant antimicrobial and antioxidant properties of the aqueous methanolic extracts of several medicinal plants. *Elettaria cardamomum* emerged as the strongest antibacterial agent, particularly effective against Gram-positive bacteria, while *Curcuma longa* showed pronounced antifungal activity against *Candida tropicalis*. Additionally, various extracts effectively scavenged DPPH and hydroxyl radicals, with *Cinnamomum verum* exhibiting the highest antioxidant activity. These findings underscore the therapeutic potential of these plants as natural alternatives to combat infections and oxidative stress, particularly in light of increasing antimicrobial resistance. Future research could explore the synergistic effects of combinations of these plants to enhance their efficacy against resistant strains of pathogens. It is important to incorporate these extracts into food, nutraceuticals, and herbal medicine, ultimately enhancing the understanding of their health benefits and potential applications in disease prevention and treatment. Additionally, studies on the potential applications of these plants in food preservation and their role in boosting immune responses could provide insights into their broader health benefits.

Data Availability Statement: Data are available from the corresponding author upon request.

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