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Antimicrobial and other biological activity of Cardamom *(Elettaria cardamomum L.)* extracts: A comparative study of aqueous, alcohol, and oil extracts

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Abstract

Objective

This study aimed to compare the chemical character, antibacterial activity, and antioxidant capacity of three distinct extracts from Elettaria cardamomum seeds: an aqueous extract, an ethanolic extract, and an essential oil. This study aimed to measure their viability as natural bioactive substances for medicinal and also purposes in food preservation.

Materials and methods

E. cardamomum seeds were extraction through aqueous methods, organic solvent (ethanol), and hydro-distillation for essential oil production. Gas Chromatography-Mass Spectrometry (GC-MS) devise was used to analyzed essential oil's molecular profile. The antimicrobial efficiency was measured against specific pathogenic bacteria using the disk diffusion method (inhibition

zones) and the Minimum Inhibitory Concentration (MIC) assay. The antioxidant capacity was measured by using the radical scavenging test called DPPH (2,2-diphenyl-1-picrylhydrazyl).

Results

The chemical study of the essential oil revealed that alpha-terpinyl acetate and 8,8′-(3-methyl-1-oxobutylidene) bis (3,6-dioxa-1,8-octanediyl) diacetate are the predominant ingredients. The aqueous extract exhibited the highest antibacterial efficacy, especially against *Staphylococcus aureus*, with an inhibition zone of 18.0 ± 0.5 mm and MIC values between 12.5 and 50 mg/mL. In contrast, the essential oil demonstrated the minimal antibacterial efficacy. The ethanolic extract exhibited superior antioxidant ability compared to other preparations, achieving the lowest IC_{50} value in µg/mL. This superiority is ascribed to the high efficacy of ethanol in extracting polar phenolic and flavonoid molecules.

Conclusion

The research reveals that the biological efficacy of E. cardamomum is significantly influenced by the extraction process employed. The aqueous extract is more useful for antibacterial uses, whilst the ethanolic extract is optimal for antioxidant reasons. These findings corroborate the conventional application of cardamom and indicate that choosing the suitable solvent is essential for maximizing its medicinal and preservation advantages in the food and pharmaceutical sectors.

Keywords: antimicrobial activity, aqueous extract, ethanolic extract**,** GC-MS, natural antimicrobials

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Introduction

In recent years, phytobiotics and medicinal plants have attracted increasing scientific interest because of their potential use as natural substitutes for synthetic additives in animal nutrition

(Amirteymoori et al., 2021; Mohammadabadi et al., 2022). These natural products, which contribute to antimicrobial, antioxidant, anticancer, and anti-inflammatory properties, are abundant in biologically active constituents such as essential oils, alkaloids, flavonoids, and phenolic compounds (Mohammadabadi et al., 2025). Phytobiotics play an important role in improving health and enhancing immune system function (Safaei et al., 2025). Use phytobiotics and medicinal plants as natural antimicrobial growth-promoting agents in place of antibiotics in feed offers numerous advantages (Khezri et al., 2025). These benefits include enhanced zootechnical efficiency parameters and suppression of specific diseases (Mohammadabadi et al., 2023), as well as antimicrobial and antioxidant properties, cholesterol-lowering effects, stimulation of digestive enzyme activity, anticancer role, and improved hepatic function (Roudbar et al., 2015). Additionally, phytobiotics contribute to the regulation of gut microbiota, thereby enhancing nutrient absorption and supporting immune function (Vahabzadeh et al., 2021). Previous studies have confirmed that incorporating these plants into the diets can increase feed consumption, improve feed conversion to muscle, and enhance physical ability (Vahabzadeh et al., 2020). Furthermore, phytobiotics are associated with reducing stress-related impacts, improving meat quality, regulating gene expression involved in cancer, and decreasing the environmental impact of animal production systems by optimizing nutrient utilization (Mohammadabadi et al., 2024). Elettaria cardamomum L, generally known as Cardamom and referred to as the "queen of spices," is a perennial herbaceous plant belonging to the Zingiberaceae family, utilized for culinary and medicinal purposes for centuries. Cardamom is historically one of the important medicines in traditional Ayurvedic and unani medications with therapeutic benefits such as digestive, anti-inflammatory, antimicrobial, antioxidant, among others that have been proved (Ahmad et al., 2011). The increased prevalence of antibiotic resistant microorganisms has led to the search for alternative antimicrobial agents. Therefore, alternative medicinal strategies like plant products are now considered potential sources of new biologically active chemicals (Cowan, 1999). The bioactive metabolites of cardamom are diverse and encompass terpenoids (including bornyl acetate and germacrone), flavonoids, alkaloids, and phenolic acids, which may contribute to its pharmacological effects. The essential oil's composition of 1,8-cineole, α-terpinyl acetate, linalool, and sabinene has demonstrated antibacterial and antioxidant properties (Singh et al., 2008). The mode of action of these compounds includes a disruption of the bacterial cell wall, repression of protein synthesis, and the blocking of microbial adherence to surfaces (Burt, 2004). Significantly, the potential of cardamom extracts in controlling the growth of multidrug-resistant bacteria has been reported (Rodrigues et al., 2020). Increased incidences of foodborne infection and negative impact of artificial food preservatives favour plant-derived natural antimicrobials and considered as

potential alternatives for ensuring food safety (Ge et al., 2022). Herbs and spices such as cardamom, have long been used for flavour induction and preservation. The decreasing the microbial count could help in enhancing the shelf life (Shan et al., 2005). In addition, the application of cardamom extract inhibiting foodborne pathogenic strains may privilege its use into natural food safety remedies (Yassin et al., 2021). The present study, investigates the in vitro antimicrobial activity of aqueous, ethanolic and oil extracts of *Elettaria cardamomum* L. against some clinically important bacteria and fungi. The GC-MS analysis will detect the principal bioactive constituents that associated to antimicrobial activity. Thus, the aim of the present study was to investigate the effect of aqueous, ethanolic and oil extracts on bacteria and biofilm formation

Materials and methods

Plant material: Dried cardamom seeds purchased from local market of Baghdad city-Iraq and authenticated by a botanist. Seeds were cleaned ground into a fine powder after proper drying with grinder.

Preparation of extracts: Three types of extracts were prepared using seed powder. To prepare aqueous extract, the powder is mixed with distilled water in 1:10 w/v proportion and heated at 60°C for 2 hours. Mixture was then allowed to filter through Whatman No. 1 filter paper, and rotary evaporator of the filtrate is carried out to obtain the aqueous extract. Ethanolic Extract was prepared by using 70% ethanol (1:10 w/v) using a Soxhlet apparatus for 8 hours. Using a rotary evaporator this extract is concentrated under reduced pressure to obtain the ethanolic extract. The cardamom essential oil was obtained through hydro-distillation using a Clevenger apparatus. The oil was stored in amber vials at 4°C until further use.

Test microorganisms: The antibiotic efficacy of each extract was evaluated against several bacterial and yeast species, including Staphylococcus aureus, Bacillus subtilis, Escherichia coli, Pseudomonas aeruginosa, and Candida albicans.

Analysis of antimicrobial properties: The antibacterial efficacy of each extract was assessed using the agar well diffusion method (Agarry et al. 2005). Mueller-Hinton agar (MHA) was produced and inoculated with a standardized microbiological suspension at a 0.5 McFarland standard to conduct the antimicrobial assay. MHA was dispensed into foundation plates within sterile standard Petri dishes. Wells with a diameter of 5 mm were created in the agar plates and filled with 100 µL of each extract at a concentration of 100 mg/mL. Plates were incubated at 37°C for 24 hours for bacterial cultures and at 30°C for 48 hours for yeast cultures. The diameter of the inhibitory zones was quantified in millimeters.

Determination of MIC (Minimum Inhibitory Concentration): minimum inhibitory concentration (MIC) values were determined in all extract by using the broth microdilution method (CLSI; 2012): Extracts were diluted in a 96-well microtiter plate at concentrations ranging from 1.25 to 200 mg/mL. Wells were injected with 100 µL of microbial suspension at a concentration of 1×10^6 CFU/mL. Plates were cultured under suitable conditions, and the minimum inhibitory concentration (MIC) was ascertained as the lowest concentration of the extract that inhibited growth, utilizing plating procedures.

Gas Chromatography-Mass Spectrometry analysis: Gas Chromatography-Mass Spectrometry (GC-MS) analysis was conducted to identify the bioactive components of the extracts. The investigation utilized a Shimadzu GC-MS machine fitted with a capillary column (DB-5MS). The analysis was carried out as demonstrated by (Nadaf et al., 2016) with slight modification in temperatures of the processes. The temperature was set at 50 °C for 3 for initial column and held at 30 min by linear increase to 300° C at 11 °C min^{-1}. 200 °C is set for the injection port and 280 °C. was maintained at GC-MS interface. The helium gas was used as carrier gas at 1 ml min^{-1} flow rate for 30 min run. Compounds were identified by comparing their mass spectra and retention indices with the NIST20 library.

Antioxidant activity assay: The DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay and the ferric reducing antioxidant power (FRAP) assay were conducted to evaluate the antioxidant capacity of the extracts (Noor et al. 2014). For the DPPH experiment, 3 mL of each extract concentration produced in methanol was combined with 1 mL of 0.1 mM methanol DPPH solution. Examine the reduced absorbance at 517 nm. The antioxidant activity was expressed as IC_{50} values, with respect to extract concentration needed to scavenge 50% of the radicals. The ferric reducing power of the extracts was evaluated by mixing them with a ferric-TPTZ reagent and measuring absorbance at 593 nm. increased absorbance indicated strong reducing power.

Antibiofilm activity: The crystal violet biofilm inhibition assay was performed to analyse antibiofilm activity of the extracts. For this experiment bacterial strains including Gram Positive *S. aureus* as well as Gram Negative *P. aeruginosa, E. coli* was cultured in 96-well plates with varying concentrations of cardamom extracts. Microplate Reader instrument using 96-well plastic microtiter plates (Hi-media). Briefly the 96-well microtiter plate was filled with 50 µL of culture suspension and 100 µL of LB broth. Then, 50 µL of all extracts with varied concentration (100, 250 and 500 µg/ml) was added to each well in the right concentrations. After those plates were kept at 25˚ C for incubation for 24 hrs. After 24 hours of incubation, wells were washed to remove planktonic cells, and biofilm was stained with crystal violet. The quantification of biofilm inhibition was determined by measuring optical density at 570 nm to (Slobodníková et al. 2016).

Results and discussion

Extract preparation: Three types of extract are used with different solvent and extraction methods. All three-extract showed versatility in the extracted products and hence pharmacological activities too.

Antimicrobial activity: The aqueous extract exhibited superior antibacterial activity compared to the ethanolic extract, however the essential oil shown no significant antibacterial impact (Table 1; Figure 1). The MIC values exhibited a same pattern, with the aqueous extract demonstrating the highest efficacy (MIC: 12.5 to 50 mg/mL), succeeded by the ethanolic extract (MIC: 25 to 100 mg/mL), while the oil extract shown negligible or no activity.

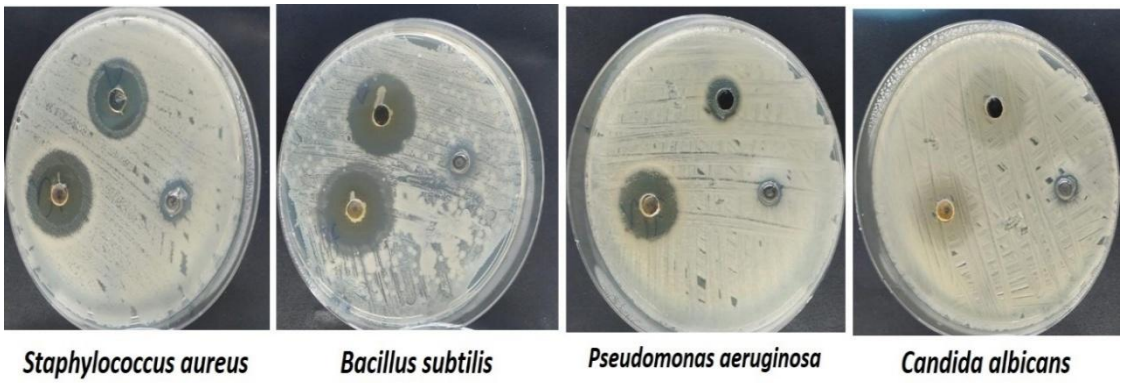

Figure 1. Antimicrobial activity of *Elettaria cardamomum L* extracts

Table 1. Comparative Table of Antimicrobial Activities

Microorganism	(Zone of Inhibition in mm)		
	Aqueous Extract	**Ethanolic Extract**	**Oil Extract**
Staphylococcus aureus	18 ± 0.5	12 ± 0.3	None
Bacillus subtilis	16 ± 0.4	10 ± 0.2	None
Escherichia coli	14 ± 0.3	9 ± 0.2	None
Pseudomonas aeruginosa	13 ± 0.4	8 ± 0.2	None
Candida albicans	12 ± 0.2	7 ± 0.2	None

Chemical metabolites obtained from cardamom exhibit potential antibacterial capabilities and successfully suppress several microbial infections (Ramadan et al., 2022). The phytochemicals encompass phenolic substances, flavonoids, alkaloids, sterols, terpenes, and tannins (Abdullah et al., 2017, 2021). These phytochemicals exert antibacterial actions through several mechanisms, including microbial growth suppression, quorum sensing interference, and biofilm inhibition. Investigations into antimicrobial properties have demonstrated that various cardamom extracts possess antimicrobial efficacy against pathogenic bacteria, including Staphylococcus aureus ATCC 8095, Listeria monocytogenes ATCC 15313, Escherichia coli ATCC 25922, and Salmonella enteritidis ATCC 13076, as well as antifungal capabilities.

Research conducted by Ramadan et al. corroborates these results (Ramadan et al., 2022; Abdullah et al., 2022).

Phytochemical composition: The aqueous extract has a greater concentration of hydrophilic flavonoids and phenolic components compared to ethanolic and oil extracts (Table 2).

GCMS analysis: From GC/MS of cardamom extracts revealed several major bioactive metabolites. Key findings include Bis(2-ethylhexyl) Bicyclo [2.2.1] heptane, 2-methyl-3-methylene-2-(4-methyl-3-pentenyl)-, Sobrerol 8-acetate, Linalyl acetate, Hexadecanoic acid, ethyl ester and Stigmasta-3,5-diene, along with other extract-specific constituents (Table 2) and GC chromatograms (Figure 2, 3, and 4).

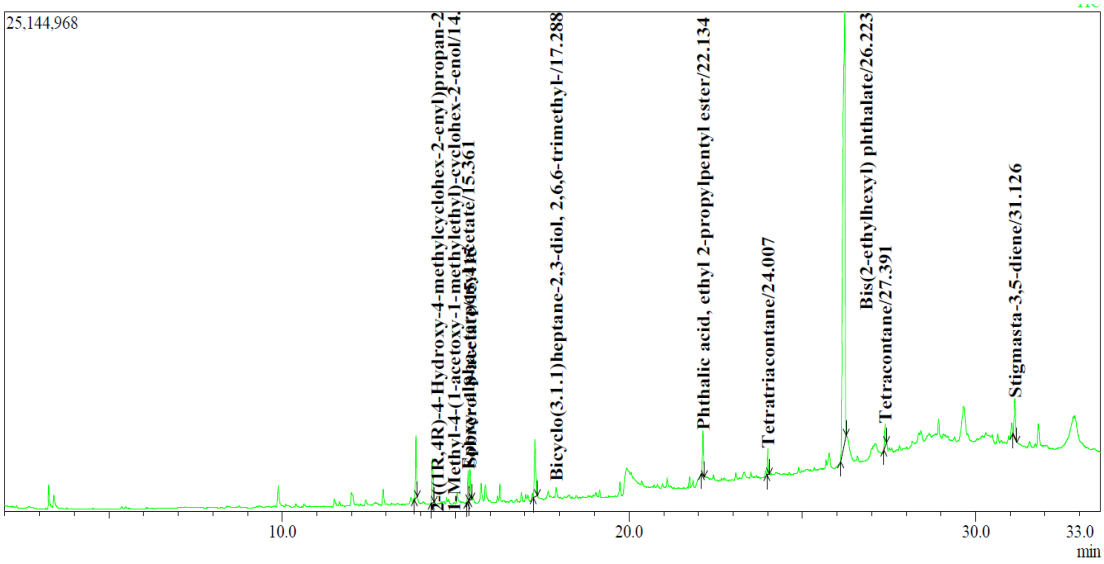

Figure 2. GCMS Chromatogram of aqueous extract of *Elettaria cardamomum L.*

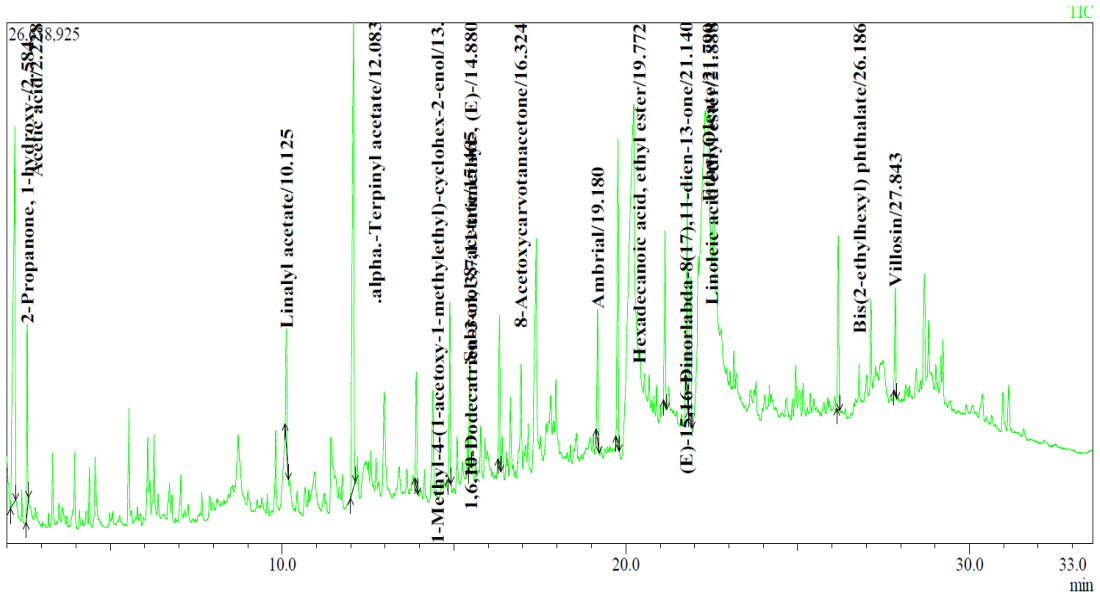

Figure 3. GCMS Chromatogram of ethanolic extract of *Elettaria cardamomum L.*

Table 2. GCMS analysis of all extract and major compound identified from the analysis

Phytochemical	Source	Retention Time (min)	m/z Value	Area%	Applications	Citation
Bicyclo[3.1.1] hept-2-ene, 2,6,6-trimethyl-	From Cardamom Oil	4.800	136	0.48	Antimicrobial, antioxidant, anti-inflammatory	Nyamwihura, & Ogungbe, 2022
2-Hexen-4-yne, 2-methyl-		4.963	94	4.08	Potential antifungal and antimicrobial activities	
Santalol, trans-beta.-		4.967	220	4.08	Aromatic, sedative, antimicrobial	Kumar et al., 2005
1,3,6-Octatriene, 3,7, dimethyl-, (Z)-		5.633	136	0.62	Fragrance, insect repellent	Api et al., 2021
Bicyclo (2.2.1) heptane, 2-methyl-3-methylene-2-(4-methyl-3-pentenyl)-		7.890	204	9.44	Antibacterial, antifungal	Nyamwihura, & Ogungbe, 2022
Bicyclo (3.1.1) heptane-2,3-diol, 2,6,6-trimethyl-		17.288	170	6.16	DHS activator, antioxidant properties	Nyamwihura, & Ogungbe, 2022
Epoxy-.alpha.-terpenyl acetate	From Hill Aqueous Extract	15.361	212	2.05	Antimicrobial, anti-cholesterol, properties, anti-diabetic,	Chowdhury & Kumar, 2020
Sobrerol 8-acetate		15.415	212	2.53	Anti-inflammatory, respiratory benefits	Castillo et al., 2023
Tetratriacontane		24.007	478	1.64	Lubricant, emollient	Sumithra & Purushothaman, 2016
Stigmasta-3,5-diene		31.126	410	4.06	Anti-diabetic, Antioxidant, cholesterol-lowering effects	Hajra et al., 2024
Linalyl acetate	From Hill Ethanol Extract	10.125	196	3.53	Aromatic, relaxant, antimicrobial	Dable-Tupas et al., 2023
α-Terpinyl acetate		12.083	196	21.23	Flavoring agent, antimicrobial	Ashokkumar et al., 2021
1-Methyl-4-(1-acetoxy-1-methylethyl)-cyclohex-2-enol		13.905	212	3.00	Antibacterial, antifungal	Chowdhury & Kumar, 2020
1,6,10-Dodecatrien-3-ol, 3,7,11-trimethyl-, (E)-		14.880	196	4.75	Fragrance, potential antimicrobial properties	Shareef et al., 2016
8-Acetoxycarvotanacetone		16.324	250	3.89	Antioxidant, antimicrobial	Vaida Vaiciulyte al., 2021
Ambrial		19.180	236	3.51	Perfume ingredient, fixative	Zhao et al., 2021
Hexadecanoic acid, ethyl ester		19.772	284	9.44	Emollient, lubricant, bioactive compound	Khatri et al., 2017
(E)-15,16-Dinorlabda-8(17),11-dien-13-one		21.140	290	4.78	Anti-inflammatory, antimicrobial	Kappen et al., 2015
Linoleic acid ethyl ester		21.888	308	5.31	Essential fatty acid, skin-conditioning agent	Arpitha et al., 2019
Villosin		27.843	420	3.09	Possible antioxidant, pharmacological potential	

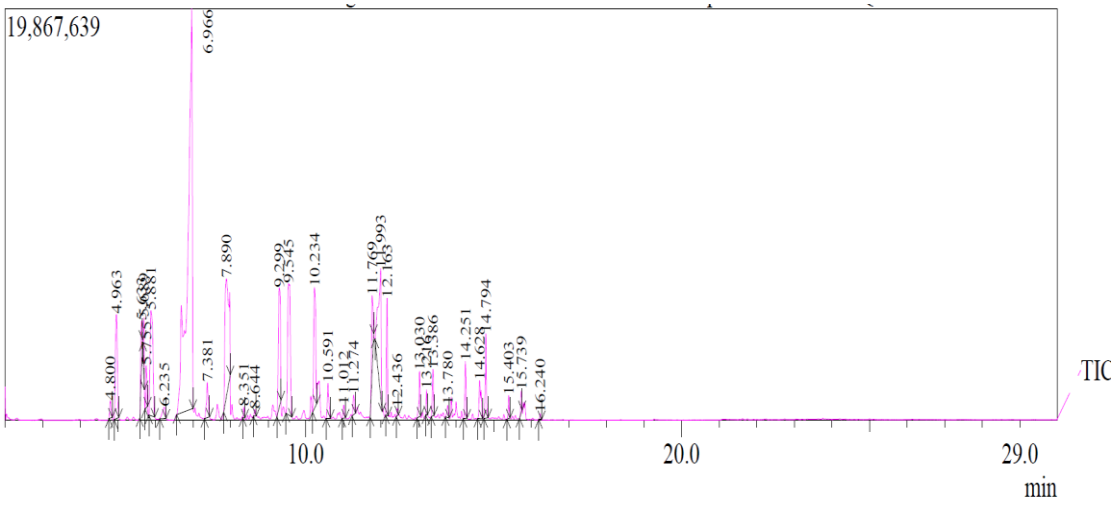

Figure 4. GCMS Chromatogram of essential oil extract of *Elettaria cardamomum L.*

The quantitative analysis of extracted phytochemicals from green and black seeds of cardamom depend on factors such as genotype, cultivation region, extraction technique, moisture content, maturity stage, and the analytical methods used for identification and quantification (Abdullah et al., 2021; Savan and Küçükbay, 2013; Joshi et al., 2013) Various advanced techniques have been employed for this purpose, including liquid chromatography-electrospray ionization quadrupole time-of-flight mass spectrometry, (HPLC) High-Performance Liquid Chromatography, (GC-FID) GC-Flame Ionization Detection, (GC) gas chromatography and (GC-MS) Gas Chromatography and Mass Spectrometry (Savan Küçükbay, 2013). Recent advancements in analytical techniques, especially gas chromatography-mass spectrometry (GC-MS), have enabled the thorough characterization of phytochemicals and metabolites found in natural products. GC-MS investigation of cardamom has discovered significant chemicals including linalool, terpinyl acetate, and 1,8-cineole, recognized for their antibacterial and aromatic properties (Singh et al., 2008). The composition of these elements' changes markedly according on the extraction method employed, with aqueous, ethanolic, and oil extracts yielding unique profiles of polar and non-polar molecules (Burt, 2004). Similar kind of results was obtained the identified compounds shows variation in each extract.

Antioxidant activity of the extracts: There was observable antioxidant action in the extracts. The highest capacity to neutralize free radicals was shown by the ethanolic extract, as shown in table 3. The existence of potent antioxidant substances was verified by the DPPH and FRAP assays, indicating that cardamom extracts may help to reduce oxidative stress and preventing cellular damage. The results show that the ethanolic extract possessed the highest antioxidant capacity, while the oil extract displayed the weakest act. Evidence suggests that phytochemicals derived from cardamom improve the body's antioxidant defense mechanisms,

mostly due to presence of phenolics compounds such as quercetin, kaempferol, pelargonidin, and luteolin, in addition to sterols compounds including tocopherols and phytosterols (Nassar et al., 2021; Ramadan et al., 2022). Previous studies have highlighted the antioxidant effects of methanolic extracts gained from green cardamom seeds and pods. To assess the link between phenolic metabolites and antioxidant potential, both parameters were quantified by using the Folin-Ciocalteu phenol reagent, linoleic acid peroxidation inhibition techniques, and the DPPH assay, respectively (Saeed et al., 2014). All tested extracts demonstrated notable antioxidant effects, with the ethanolic extract showing superior free radical scavenging activity. The DPPH and FRAP assays confirmed the presence of potent antioxidant compounds, suggesting that cardamom extracts may play a role in reducing oxidative stress and preventing cellular damage.

Table 3. Analysis of antioxidant activity of three extracts

Extract Type	DPPH IC50 (µg/mL)	FRAP (Absorbance at 593 nm)
Aqueous	48.5 ± 1.2	0.72 ± 0.05
Ethanolic	32.1 ± 0.9	1.02 ± 0.07
Oil	65.3 ± 1.5	0.48 ± 0.03

Anti-biofilm activity: Biofilm refers to a multispecies or single species group of microbes that are embedded in a self-produced extracellular matrix, which provides the microorganisms a barrier against the human immune system, antimicrobial agents and compounds, and unfavourable physicochemical environments. The importance of biofilm development will be demonstrated in the context of nosocomial and foodborne infections. Therefore the search for organic bioactive compounds has become greatest need as a safer option for traditional antibiotics. The formation of biofilms is controlled by quorum sensing, a type of communication among bacteria through exchange of signal chemicals. The antibiofilm studies demonstrated that cardamom extracts exhibited strong antibiofilm activity against *P. aeruginosa* and *S. aureus*. The ethanolic extract exhibited the most antibiofilm activity, perhaps because it contains higher levels of phenolic and flavonoid compounds (Table 4). Results emphasize the therapeutic potential of cardamom in combating biofilm-associated infections and boosting the activity of conventional antimicrobials. These findings are evidence that the ethanolic extract presented the most inhibitive antibiofilm activity, successively by the aqueous extract, but the oil extract showed the least effect in preventing the biofilm growth. Cardamom extracts inhibited biofilm formation in *S. aureus* and *P. aeruginosa* in a concentration-dependent manner according to the antibiofilm assays. The highest antibiofilm activity of the ethanolic extract may be attributed to

its high content of phenolic and flavonoid compounds. These results indicate the efficacy of cardamom extracts in the management of biofilm-mediated infections, and add credence to improving the efficacy of the available antibiofilm agents.

Table 4. The Antibiofilm activity of extracts

Extract Type	% Biofilm Inhibition (*S. aureus*)	% Biofilm Inhibition (*P. aeruginosa*)
Aqueous	58.7 ± 2.1	46.9 ± 1.8
Ethanolic	72.3 ± 1.5	63.4 ± 2.0
Oil	39.5 ± 1.7	28.7 ± 1.4

Comparative analysis: The strong antimicrobial effect of the aqueous extract is due to the abundance of phenolic compounds, especially 1-Methyl-4-(1-acetoxy-1-methylethyl)-cyclohex-2-enol and Stigmasta-3,5-diene, as they express powerful antioxidant and potential antimicrobial activities. The ethanolic extract had a moderate result and α-Terpinyl acetate played an important role in the antimicrobial activity. The volatile compound-rich oil, especially of Sabinene Toyo, had less antimicrobial power but possibly anti-inflammatory and fragrance applications. These dissimilarities highlight the impact of extraction techniques on the phytochemical composition and bioactivity of cardamom.

Conclusion: The present study emphasizes potential of cardamom extracts for their antimicrobial activity wherein the aqueous extract showed maximum antimicrobial activity. GC-MS analysis determined the presence of important bioactive compounds responsible for the above effects. These results endorse the applicability of cardamom as a natural antimicrobial agent and its great significance in pharmaceutical and food industries. More studies are necessary to identify the active ingredients and their exact mechanisms of action. Phytochemical and biological properties of cardamom extracts are explored and it is suggested that these results add to the current literature that supports use of natural plant-based anti-microbials as suitable alternatives to synthetic compounds in food safety and healthcare.

Author Contributions

Marwa Lafta Jabur contributed to the conceptualization, study design, data collection, and drafting of the manuscript. Lubna Amer Mohammed performed the data analysis, statistical evaluations, and preparation of tables and figures. Khetam Habeeb Rasool and Sajjad Yaquob Yuosif carried out sample processing, laboratory experiments, validation of results, and contributed to the methodology section. Shahrazad Ahmed Khalaf supervised the project, provided critical manuscript revisions, and approved the final version as the corresponding author.

Data availability statement

Data found in authors.

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Ethical considerations

Not applicable.

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Conflict of interest

There is no conflict of interest.

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فعالیت ضدمیکروبی و سایر فعالیت‌های زیستی عصاره‌های هل (Elettaria cardamomum L.): مطالعه‌ای مقایسه‌ای بین عصاره آبی، الکلی و روغن اسانسی

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چکیده

هدف: هدف اصلی این پژوهش، مقایسه ویژگی‌های شیمیایی، فعالیت ضدباکتریایی و ظرفیت آنتی‌اکسیدانی سه نوع عصاره مختلف حاصل از دانه‌های *Elettaria cardamomum* شامل عصاره آبی، عصاره اتانولی و روغن اسانسی بود. این مطالعه با هدف ارزیابی قابلیت استفاده از این عصاره‌ها به‌عنوان ترکیبات زیست‌فعال طبیعی در کاربردهای دارویی و همچنین نگهداری مواد غذایی انجام شد.

مواد و روش‌ها: دانه‌های *E. cardamomum* به‌وسیله روش استخراج آبی، حلال آلی (اتانول) و تقطیر با آب برای تولید روغن اسانسی استخراج شدند. پروفایل مولکولی روغن اسانسی با استفاده از دستگاه کروماتوگرافی گازی–طیف‌سنجی جرمی (GC-MS) مورد تجزیه‌وتحلیل قرار گرفت. اثربخشی ضدمیکروبی عصاره‌ها در برابر برخی باکتری‌های بیماری‌زا با استفاده از روش انتشار دیسکی

(اندازه‌گیری قطر هاله مهاری) و آزمون حداقل غلظت مهاری (MIC) ارزیابی شد. ظرفیت آنتی‌اکسیدانی با استفاده از آزمون مهار رادیکال آزاد DPPH (۲,۲–دی‌فنیل–۱–پیکریل‌هیدرازیل) اندازه‌گیری گردید.

نتایج: بررسی شیمیایی روغن اسانسی نشان داد که آلفا–ترپینیل استات و ترکیب 8,8′-(3-methyl-1-oxobutylidene) bis (3,6-dioxa-1,8-octanediyl) اجزای غالب آن هستند. عصاره آبی بیشترین اثر ضدباکتریایی را، به‌ویژه علیه *Staphylococcus aureus*، نشان داد؛ به‌طوری‌که قطر هاله مهاری برابر با ۱۸.۰ ± ۰.۵ میلی‌متر و مقادیر MIC در بازه ۱۲.۵ تا ۵۰ میلی‌گرم بر میلی‌لیتر بود. در مقابل، روغن اسانسی کمترین فعالیت ضدباکتریایی را نشان داد. عصاره اتانولی در مقایسه با سایر عصاره‌ها دارای بیشترین توان آنتی‌اکسیدانی بود و کمترین مقدار IC_{50} (بر حسب میکروگرم بر میلی‌لیتر) را ثبت کرد. این برتری به توان بالای اتانول در استخراج ترکیبات فنولی و فلاونوئیدی قطبی نسبت داده می‌شود.

نتیجه‌گیری: نتایج این پژوهش نشان می‌دهد که کارایی زیستی *E. cardamomum* به‌طور قابل توجهی تحت تأثیر روش استخراج مورد استفاده قرار دارد. عصاره آبی برای کاربردهای ضدباکتریایی مناسب‌تر است، در حالی‌که عصاره اتانولی برای اهداف آنتی‌اکسیدانی انتخاب بهینه محسوب می‌شود. این یافته‌ها کاربرد سنتی هل را تأیید کرده و نشان می‌دهد که انتخاب حلال مناسب نقش اساسی در به حداکثر رساندن مزایای دارویی و نگهدارندگی آن در صنایع غذایی و داروسازی دارد.

کلمات کلیدی: فعالیت ضدمیکروبی، عصاره آبی، عصاره اتانولی، ضدمیکروب‌های طبیعی، GC-MS

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