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Star anise volatile oil's dual role: Investigating its antioxidant and DNA-cleaving actions against *Staphylococcus aureus*

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Abstract

Objective

The growing threat of antibiotic resistance, exclusively in *Staphylococcus aureus*, necessitates the expansion of novel therapeutic attitudes. The aim of the current investigation was to assess the dual functional potential of star anise (*Illicium verum*) volatile oil in aspect of its antioxidant effects and a DNA-cleaving effect. Researches have shown that star anise has been traditionally applied as a culinary spice and in folk medicine for treating coughs and alleviating pain. But, the exact mechanism of the antibacterial activity of the essential oil is still unknown.

Materials and methods

For performing the analytical and biological assays, Gas Chromatography-Mass Spectrometry (GC-MS), total antioxidant capacity, DPPH radical scavenging assay, FRAP assay, and DNA cleavage assay were used. Bacterial isolates were derived from diabetic foot ulcers, recognized, and genetically described applying 16S rRNA gene sequencing, and then mutation analysis was used. The Swiss ADME software was used to analyze physicochemical attributes, containing molecular weight, Log P, hydrogen bond donors and acceptors, and topological polar surface area (TPSA).

Results

GC-MS analysis disclosed a compound chemical composition dominated by anethole, with substantial amounts of estragole, limonene, and anisaldehyde. The DPPH assay revealed effective radical-scavenging activity with an IC_{50} of 7.2% (v/v), in comparison to 3.5% (v/v) for vitamin E. The FRAP analysis demonstrated its dose-dependent antioxidant activity. A novel bacterial isolate was identified, named novel *S. aureus* strain, and then registered it in the GenBank with the accession number PX068377.1. The absence of a DNA band in electrophoresis subsequent the DNA cleavage assay illustrated meaningful genomic degradation. This could be due to the strong genotoxic effects of the reaction due to the low molecular weight and high hydrophobicity of the volatile oil components, which facilitate their rapid penetration into the membrane and subsequent destruction of the damaged nucleic acid.

Conclusion

Due to the strong antioxidant and genotoxic properties of star anise essential oil demonstrated in this study, it can be introduced as a potential natural and indigenous antimicrobial agent, especially specifically against antibiotic-resistant bacteria.

Keywords: anethole, diabetic foot ulcer, GC–MS, *Illicium verum*, *Staphylococcus aureus*

Paper Type: Research Paper.

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Introduction

The most important sources of bioactive compounds are medicinal plants. Essential oils are one of the most vital compounds contained in it. The average level and chemical constituents of these oils may differ greatly from the individual factors of plant species, genetic distinguish of the varieties, development stages, growth conditions, and extraction methods (Moghaddam et al., 2023). Among the extraction techniques, hydrodistillation is to some extent the most widely used approach to isolating essential oils from highly specific secretory glands of fruits, flowers, and leaves in a variety of plant parts. The consequencing distillates retain the distinctive volatile secondary metabolites of the source plants, yielding essential oils with strong and characteristic

characteristic aromas that reflect their botanical origin (Shaabanetal, 2012). Volatile oils, which have been used for thousands of years therapeutically are produced by steam or other distillation methods. Aromatic plants and their volatile oils have along history of being valued for their preservative, aromatic, and medicinal characteristics. Research recently proved that the therapeutic outcomes of these oils frequently result from the synergistic interaction of two or more terrible constituents that exist in important concentrations rather than from a single compound. For example, eucalyptus oil is commonly known for its analgesic and antitussive activities, while anise and peppermint oils are well-known for their carminative properties Mohamed and (Alotaibi, 2023). The antimicrobial activity of volatile oil is nothing new; it precedes modern healthcare applications. In the 14th century's great plague, for example, essential oils were utilized as the first-line barrier pharmaceuticals against *Yersinia pestis* (Abers et al., 2021). However, while the historical use of volatile oil has been well-documented for centuries due to their aromatic and antimicrobial properties, more recent scientific research has focused on their potential uses in treating concurrent health issues. Chronic metabolic illnesses such as diabetes mellitus and proved that the continued dominance of antibiotic cleaners against bacterial infections. Almost 30% of despite the fact that there was a clear understanding of how they worked, Chronic metabolic diseases, like diabetes mellitus, and the global rise of antibiotic-resistant bacterial infections continue to pose serious public health threats. Almost 30% of diabetic patients are expected to undergo expansion of foot ulcers in their lifetime, and these ulcers are particularly vulnerable to secondary infections that can progress into serious subsequent complications. The pathogens causing this kind of disease are usually polymicrobial, comprising both Gram-positive and Gram-negative species, with Gram-positive *Staphylococcus aureus* being the most frequently extracted species (Vecchio et al., 2016). The dried fruits of *Illicium verum*, medicinal plant commonly known as star anise, are rich in volatile oils and others phytoconstituents. The Volatile oils of these compounds, primarily extracted from the plant's distinctive star-shaped fruit, have a variety of pharmacological effects. An evergreen plant with shiny, leathery leaves and solitary flowers *I.verum* produces fruits that grow together to form a star-shaped capsular aggregate fruit. popularly known as Chinese star anise (Wong et al., 2014). Star anise flower oil has a strong scent and taste that is well-known. It has been extensively studied for its antibacterial action, which has been attributed to the active component anethole (Noumi et al., 2023). In terms of chemistry, the oil includes various critical constituents, including anethole, limonene, terpineol, and estragole, thought to contribute to its potent antimicrobial properties. The growing emergence of antibiotic-resistant microorganisms has urged the search for novel antimicrobial agents derived from autochthonous sources. Essential oils are particularly promising because of their complex nature and several action mechanisms that may impede the growth of bacterial resistance. However, the exact means by which oils direct their antibacterial responses remain partly obscure. Therefore, one of the crucial elements that require additional investigation is the means by which the essential oil components interact with bacterial DNA, prompting potential genomic extinction. Several reports have stated the antimicrobial activity of *I. verum*; few, however, have conducted an analysis of its genotoxic reaction on bacterial DNA, exclusively in clinically significant species such as *S. aureus*. The primary biological activity of star anise is proposed to be attributable to its great phenylpropanoid content, in particular anethole, which provides to both its antioxidant and antimicrobial activity (Heravi et al., 2019), suggests promising results although the plant has interesting pharmacological characteristics, the chemical composition and antioxidant capacity of its essential oil differ widely with origin, climate, and culture. Star anise based or sold in Southern Iraq, in Basrah region. Thus, assessing this way of samples can investigate a fresh insight into the connection among chemical composition, antioxidant ability, and antibacterial mechanism. The present study therefore, aimed to fill up these information gaps by conducting a dual assessment of star anise essential oils, antioxidant activity and DNA-damaging potential on *S. aureus* extracted from diabetic foot ulcer infections. Gas Chromatography -Mass Spectrometry was used to identify and quantify the major chemical components of the oil, assays were used to test the oil’s antioxidant and genotoxic effects. Understanding how these volatile ligands interact with bacterial DNA may provide a mechanism basis for their antibacterial. The results from this investigation participate to the growing body of evidence supporting the use of plant-derived essential oils as indigenous therapeutic alternatives to synthetic antibiotics. Furthermore, they may propose worth perspectives for expanding novel strategies to combat antibiotic-resistant pathogens, exclusively those related to chronic infections in diabetic patients.

Materials and methods

Plant material and extraction of volatile oil: Dried fruits of star anise were purchased from local markets in Basrah City, Basrah Governorate, Iraq. The fruits were cleaned and air-dried. An electric grinder was used to convert ground into a fine powder applying. A total of 40 g of the powdered sample was subjected to hydrodistillation applying a Clevenger-type apparatus. Each sample was distilled with 400 mL of distilled water for 3 hours on a heating mantle. The volatile oil separated as an upper layer on the aqueous phase and was carefully gathered applying a Pasteur pipette to avoid water contamination. Below equation (Fagbemi et al., 2021) was used to calculate the oil yield.

Oil yield (%) = (Mass of extracted oil / Mass of pulverized plant) ×100

Gas chromatography-mass spectrometry (GC-MS) analysis: applying A Gas Chromatography–Mass Spectrometry (GC-MS) system (Agilent Technologies 7890B GC coupled to an Agilent 5977A Mass Selective Detector with Electron Ionization, EI) was used to analyze the chemical composition of the star anise volatile oil. All analyses were managed at the Basra Oil Company Laboratory under controlled situations to ensure accurate separation and reliable compound identifying. A high-efficiency HP-5ms fused silica capillary column (30 m × 0.25 mm i.d., 0.25 µm film thickness) was used to achieve the chromatographic separation. The oven temperature was programmed as follows: initial temperature 40 °C (held for 5 min), improved to 300 °C at a rate of 8 °C min^{-1}, and held at the final temperature for 20 min. Ultra-high-purity helium (99.999%) was applied as the carrier gas at a constant flow rate of 1 mL/min with a purge flow of 3 mL/min. The injection volume was 0.5 µL, with an injector temperature of 290 °C. Samples were introduced in pulsed splitless mode to maximize compound diagnosis. An ion source temperature of 230 °C was used to operate the mass spectrometer. Data were acquired over a mass range of 44-750 m/z with a scan speed of 1562 amu s^{-1}. Identifying of individual components was achieved by comparing their mass spectra with those in the NIST (2014 and 2020) spectral libraries. Tentative compound identifying was based on spectral matching and retention time data.

Determination of total antioxidant capacity: The phosphomolybdenum method as described by Jafri et al. (2017), with slight modifications was used to determine the total antioxidant capacity of the volatile oil identified applying. The reagent solution was prepared by mixing 0.6 M sulfuric acid, 28 mM sodium phosphate, and 4 mM ammonium molybdate. A 1.0 mL aliquot of the oil sample was added to 3.0 mL of the reagent mixture in test tubes. The tubes were capped and incubated in a water bath at 95 °C for 90 min to facilitate the depletion reaction. After cooling to room temperature, the absorbance of each sample was calculated at 695 nm applying a UV-Visible spectrophotometer. A reagent blank, prepared in the same manner without the sample, was applied for baseline correction. Outcomes were expressed as milligrams of ascorbic acid equivalents (AAE) per milliliter of volatile oil.

DPPH radical scavenging assay: The DPPH (2,2-diphenyl-1-picrylhydrazyl) free radical scavenging assay, following the procedure of Kalaisezhiyen and Sasikumar (2015) was used to evaluate the antioxidant activity of the volatile oil. A freshly prepared 0.8 mM DPPH solution exhibiting a deep violet color was applied as the radical source. For each test, 1.0 mL of the oil sample was mixed with 1.0 mL of DPPH solution at concentrations ranging from 0.5% to 10% (v/v). The mixtures were gently shaken, protected from light, and left to stand at room temperature for 30 min to permit the antioxidant constituents to react with DPPH radicals. The depletion in color intensity was calculated at 517 nm applying a spectrophotometer. Vitamin E (α-tocopherol) was applied as a reference antioxidant under identical situations. Below formula was used to calculate the percentage of radical scavenging activity.

$$\% \text{ Inhibition} = [(A_0 - A_1) / A_0] \times 100$$

where A_0 is the absorbance of the control (DPPH solution without sample) and A_1 is the absorbance in the presence of the volatile oil.

Determination of ferric reducing antioxidant power (FRAP Assay): The ferricyanide depletion method based on the depletion of Fe^{3+} to Fe^{2+} by antioxidant compounds exist in the sample was used to determine the ferric reducing antioxidant power (FRAP) of the volatile oil, indicative of its electron-donating capability. Volatile oil samples were prepared at concentrations ranging from 0.5% to 10% (v/v). A 1.0 mL aliquot of each concentration was mixed with phosphate buffer (0.2 M, pH 6.6) and potassium ferricyanide [$K_3Fe(CN)_6$]. The mixtures were incubated at 50 °C for 20 min to permit depletion of Fe^{3+} ions. Termination of the reaction was done by the addition of 2.5 mL of 10% trichloroacetic acid, followed by centrifugation at 9,500 rpm for 10 min to get a clear supernatant. Next, 2.5 mL of the supernatant was mixed with an equivalent quantity of deionized water and 0.5 mL of 0.1% ferric chloride. The formation of the Prussian blue-colored compound revealed the depletion of ferric ions. The absorbance of each mixture was read at 700 nm using a UV–Visible spectrophotometer. Those samples showing higher absorbance values were estimated to be rich in reducing capacities. Vitamin E (α-tocopherol) was applied as a reference standard to validate the assay efficiency (Salar et al., 2015).

Isolation, genetic identification, and DNA cleavage activity of the bacterial strain: A clinical specimen was gathered from a patient with a diabetic foot ulcer and applied for bacterial isolation. Gram's staining technique was used to describe the isolate and the microscope was applied to confirm its cell morphology, Gram reaction, and culture purity (Photolo et al., 2020). For molecular identification, the bacterium was cultured, and genomic DNA (gDNA) was extracted applying the FAVORGEN DNA extraction kit (FAVORGEN Biotech Corp., Taiwan) subsequent the manufacturer's instructions. The extracted DNA acted as the template for evaluating the DNA-damaging reaction of the star anise volatile oil and for taxonomic identification via amplification of the 16S rRNA gene applying polymerase chain reaction (PCR). The universal primers applied for 16S rRNA gene amplification were: Forward primer: 5′-AGAGTTTGATCCTGGC-3′
Reverse primer: 5′-GGTTACCTTGTTACGACTT-3′.

Amplification of the 16S rRNA gene by PCR: A standard PCR protocol in a final reaction volume of 25 µL was used to amplify the 16S rRNA gene. The reaction mixture contained 2 µL of genomic DNA template, 12.5 µL of GoTaq® Green Master Mix (Promega, USA), 1 µL each of forward and reverse primers (10 pmol/µL), and 8.8 µL of nuclease-free water. PCR amplification was carried out under the subsequent thermal conditions: an initial denaturation at 94 °C for 2 min, followed by 35 cycles of denaturation at 94 °C for 30 s, primer annealing at 51.8 °C for 45 s, and extension at 72 °C for 90 s. To ensure complete synthesis of all DNA fragments, a final extension step was carried out at 72 °C for 5 min.

Agarose gel electrophoresis: The electrophoresis on a 2% (w/v) agarose gel containing ethidium bromide (0.5 µg/mL) was used to analyze PCR products. A 5 µL aliquot of each amplified sample was loaded into the gel alongside a 1 kb DNA ladder (Bioneer, Korea) as a molecular weight marker. Electrophoresis was managed in 1× TBE buffer, and DNA bands were visualized under UV illumination applying a gel documentation system. A clear band at almost 1,500 bp affirmed successful amplification of the 16S rRNA gene fragment.

16S rRNA gene sequencing and bioinformatic analysis: The purified PCR product was submitted for sequencing at Macrogen Inc. (Seoul, South Korea) applying an automated DNA sequencer. The derived nucleotide sequence was analyzed applying the Basic Local Alignment Search Tool (BLAST) algorithm to identify the most closely related species by comparison with sequences in the NCBI GenBank database (https://blast.ncbi.nlm.nih.gov).

Phylogenetic analysis: The 16S rRNA gene sequence derived from the bacterial isolate was in comparison to homologous sequences from reference strains derived from the NCBI GenBank database. The alignment included sequences ranging from 476 to 678 base pairs in length. The Molecular Evolutionary Genetics Analysis (MEGA) software, version 12 was used to infer phylogenetic relationships. The evolutionary tree was constructed based on sequence alignments generated by the ClustalW algorithm and evaluated applying the neighbor-joining method. Bootstrap analysis with 1,000 replicates was carried out to evaluate the robustness of the inferred phylogenetic relationships.

Evaluation of DNA cleavage activity: Agarose gel electrophoresis subsequent the protocol described by Dong et al. (2017), with minor modifications was used to evaluate the DNA cleavage activity of the star anise volatile oil. The reaction of the oil on bacterial genomic DNA was evaluated in vitro at three concentrations. The highest concentration corresponded to undiluted (100% v/v) volatile oil, while two additional test concentrations (50% and 25% v/v) were prepared by serial dilution in dimethyl sulfoxide (DMSO). For each assay, 5 µL of bacterial genomic DNA extracted from the *S. aureus* isolate was incubated with the designated oil concentration at 37 °C for 2 h. After incubation, DNA samples were mixed with an equal volume of 1:1 bromophenol blue loading dye and analyzed by electrophoresis on a 1% (w/v) agarose gel containing ethidium bromide (0.5 µg/mL). Untreated DNA and DNA given treatment with DMSO alone acted as negative controls. Electrophoresis was carried out in 1× Tris–borate–EDTA (TBE) buffer (pH

8.0) at 80 V for 45 min. DNA migration patterns were visualized under ultraviolet illumination applying a gel documentation system, and the consequence gels were photographed for analysis.

Chemical and physicochemical characterization of major volatile oil components: To survey the biological potential of the principal constituents recognized by GC-MS analysis, a virtual screening approach was carried out applying the Swiss ADME online platform (http://www.swissadme.ch). This web-based tool predicts drug-likeness, pharmacokinetic behavior, and physicochemical attributes of small molecules. The molecular framework as an indicator of molecular weight, the logarithm of the partition coefficient LogP as an indicator of lipophilicity, the number of hydrogen atoms, the number of acceptors, and the topological polar surface area were used for the calculation. These parameters provide an understanding of which molecular features affect bioavailability, membrane permeability, and biological activity. **Statistical examination:** All experimental data were statistically processed using GraphPad Prism software, version 8.0.1. The results are presented as mean ± standard deviation of at least three independent processes. Statistical significance between groups was determined using parametric analysis by Student's t-test. A p-value of less than 0.05 was considered statistically significant.

Results

Volatile oil yield: Under this method, 5% of volatile oil was found. This yield was form 2mL extraction of a 40g sample, and 5mL extraction of a 100g sample during the 3-hour distillation phase of.

Gas chromatography-mass spectrometry analysis: found 24 compounds that add up to almost 98.5 % of total oil Table 1. It included anethole as the dominant compound that adds up to 60%of total phenylpropanoids 86.56%. Additional compounds include terpenoids 10.6%, aromatic ketones 2.04%, fatty acids 1.08%, halogenated alkanes 0.71%. Table 1 shows each separate chemical compound of a class, and Figure 2- GC-MS chromatogram -shows the retention peaks of all identified compounds.

Total antioxidant capacity TAC: By applying the phosphomolybdenum method, it was 4.2 mg AAE/mL TAC. By applying the known density of star anise oil 0.98 g/mL, the converted value was 4.31 mg AAE/g. This was done to allow comparison with previously reported values.

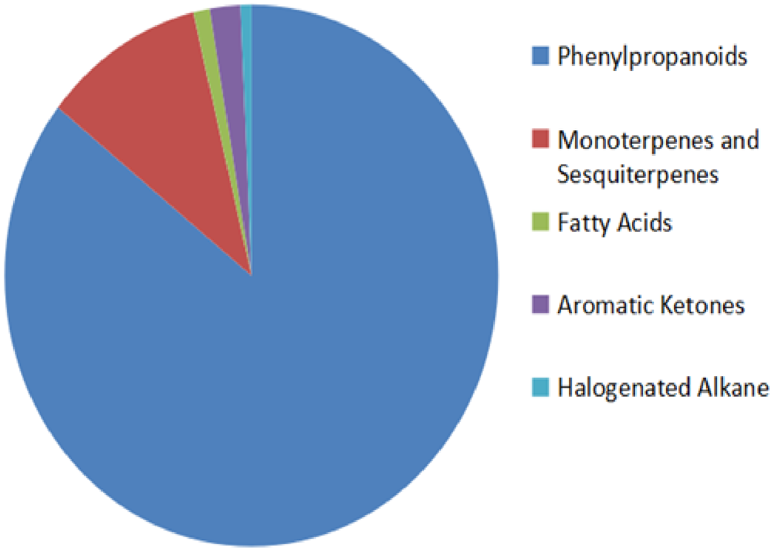

Figure 1. Composition of volatile oil compounds by chemical class

Table 1. Chemical composition of the extracted volatile oil as identified by GC–MS analysis

Peak Number	Chemical Name	Retention Time	Area	Area Pct
1	.alpha.-Pinene	8.612	2.73464e+06	0.425
2	3-Carene	10.324	2.83217e+06	0.4402
3	D-Limonene	10.733	2.73011e+07	4.2429
4	Linalool	12.052	5.12374e+06	0.7963
5	3-Cyclohexen-1-ol, 4-methyl-1-(1-methylethyl)-, (R)-	13.38	2.27205e+06	0.3531
6	.alpha.-Terpineol	13.584	3.94136e+06	0.6125
7	Estragole	13.686	3.84419e+07	5.9744
8	Anethole	14.503	5.13603e+06	0.7982
9	Benzaldehyde, 4-methoxy-	14.605	4.78141e+07	7.4309
10	Anethole	15.116	3.92423e+08	60.9877
12	2-Propanone, 1-(4-methoxyphenyl)-	16.357	9.23276e+06	1.4349
13	trans-.alpha.-Bergamotene	16.75	2.86029e+06	0.4445
14	Caryophyllene	16.891	3.0518e+06	0.4743
15	trans-.alpha.-Bergamotene	17.009	6.4054e+06	0.9955
16	1-Propanone, 1-(4-methoxyphenyl)-	17.229	3.86548e+06	0.6007
17	cis-.beta.-Farnesene	17.315	2.07813e+06	0.323
19	.beta.-Bisabolene	17.905	2.08e+06	0.3233
20	Naphthalene, 1,2,3,5,6,8a-hexahydro-4,7-dimethyl-1-(1-methylethyl)-, (1S-cis)-	18.148	2.41521e+06	0.3754
21	trans-Nerolidyl formate	18.525	2.25577e+06	0.3506
22	Pentane, 1-bromo-5-chloro-	19.57	4.58842e+06	0.7131
23	.alpha.-Cadinol	19.735	1.97853e+06	0.3075
24	1-(3-Methyl-2-butenoxy)-4-(1-propenyl)benzene	19.915	6.00796e+07	9.3372
25	n-Hexadecanoic acid	22.736	4.5954e+06	0.7142
27	Oleic Acid	24.401	2.34328e+06	0.3642

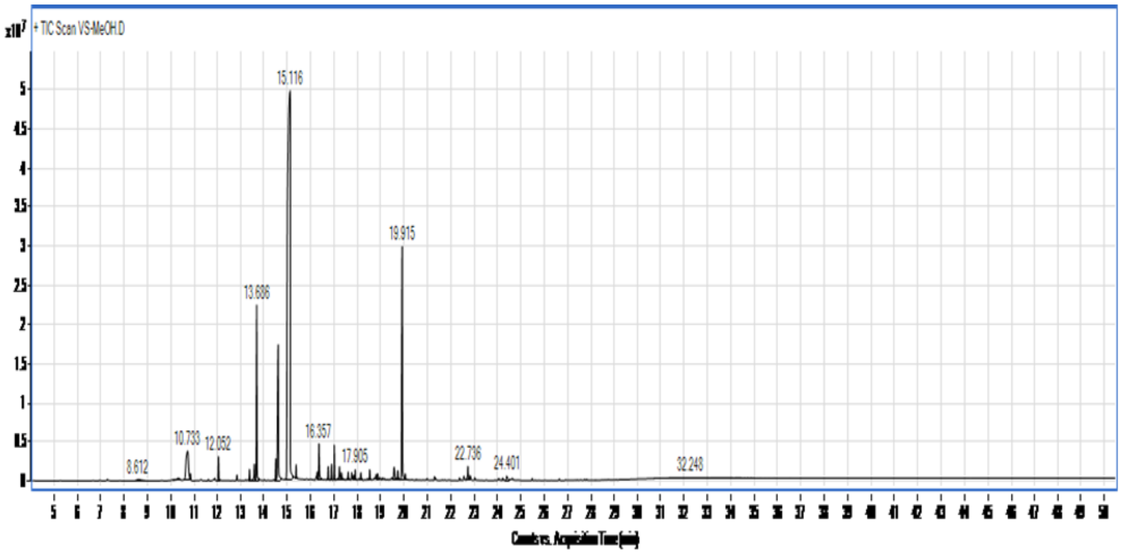

Figure 2. GC-MS chromatogram of the extracted volatile oil

DPPH radical scavenging activity: DPPH was carried out to assess the free radical scavenging capacity of the extracted volatile oil, and it demonstrated significant antioxidant activities. The IC_{50}value for volatile oil was 7.2% v/v, and in comparison, vitamin E standard exhibited the $IC_{50}$of 3.5% v/v. Although volatile oil gave the scavenging inhibitory action in the case of vitamin E, statistical analysis via t-test showed that it was not significantly different from the vitamin E assay. The general mechanism of radical scavenging by the tested antioxidant occurs as a result of hydrogen atom donating from the antioxidant molecules causes the violet DPPH• radical to be reduced to yellow DPPH-H via the reaction; thus, *DPPH• is a stable 2,2-diphenyl-1-picrylhydrazyl radical and is thus violet in color. DPPH-H (yellow): This is the decreased form of DPPH, 2,2-diphenyl-1-picrylhydrazine. The outcomes are shown in Figure 3.

Ferric reducing antioxidant power (FRAP Assay): The ferric reducing antioxidant power of the extracted volatile oil was evaluated applying the FRAP assay. The outcomes revealed a concentration-dependent improve in reducing power for both the volatile oil and the Vitamin E standard. Statistical analysis applying a t-test illustrated a meaningful difference between the antioxidant capacities of the volatile oil and Vitamin E ($p = 0.008$). These outcomes are shown in Figure 4.

Genetic identification of bacterial isolates: Gel electrophoresis of the 16S rRNA gene amplification yielded a product of almost 1,500 base pairs (Figure 5). Sequence analysis affirmed that the isolate displays a novel strain of *Staphylococcus aureus*, designated Staphylococcus aureus strain En.A.Sa.A.Ra.A.1, and deposited in the GenBank database under accession number PX068377.1. Comparative analysis disclosed 99% nucleotide identity with *S. aureus* strain LAS3, with the staying 1% displaying unique point mutations, containing both transitions and transversions (Table 2). Alignment of the 16S rRNA gene showing the positions of these point mutations is presented in Figure 6, while the phylogenetic relationships of the novel strain in comparison to reference strains are shown in Figure 7.

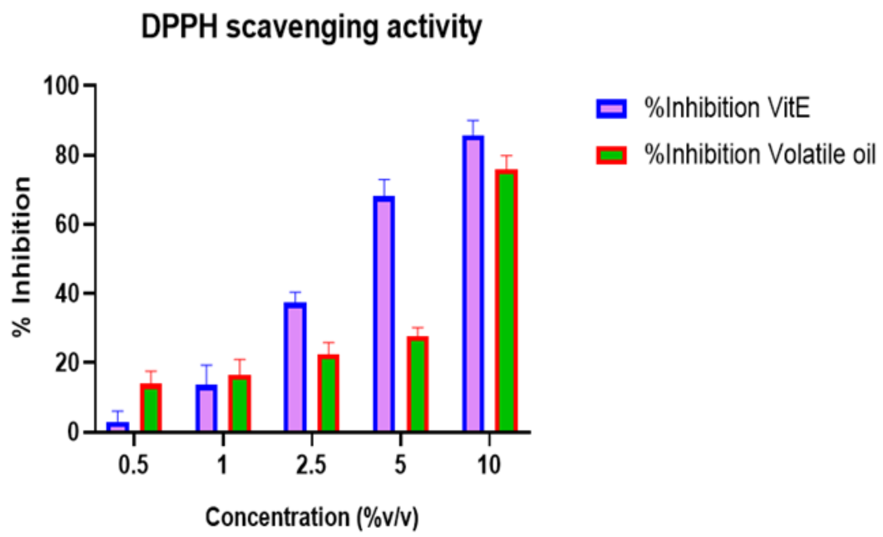

Figure 3. DPPH radical scavenging activity of the extracted volatile oil in comparison to the Vitamin E standard

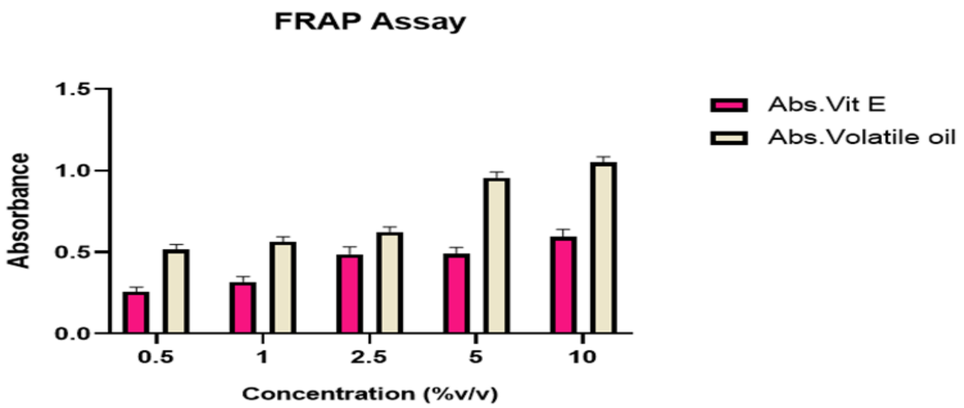

Figure 4. FRAP assay outcomes showing the ferric reducing power of the extracted volatile oil and Vitamin E standard

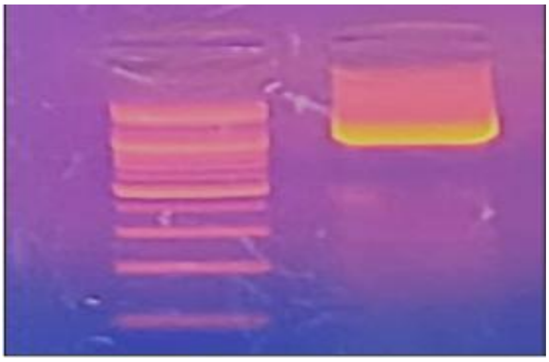

Figure 5. Gel electrophoresis of 16S rRNA gene amplification (~1,500 bp)

Table 2. Summary of transition and transversion mutations in *Staphylococcus aureus* strain En.A.Sa.A.Ra.A.1 (ID: PX068377.1)

Type of Substitution	Location	Nucleotide	Source	Sequence ID (reference)	Sequence ID (submission)
Transversion	549	G→C	*S. aureus*	PQ740492.1	PX068377.1
Transition	486	G→A			
Transversion	479	C→A			
Transition	457	G→A			
Transversion	454	G→T			

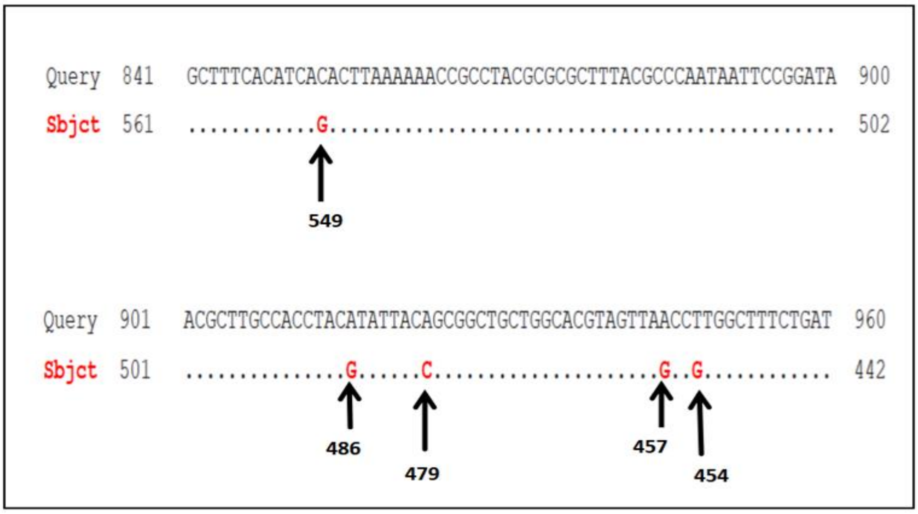

Figure 6. Alignment denoting transition and transversion point mutations in the 16S rRNA gene of *S. aureus* strain En.A.Sa.A.Ra.A.1

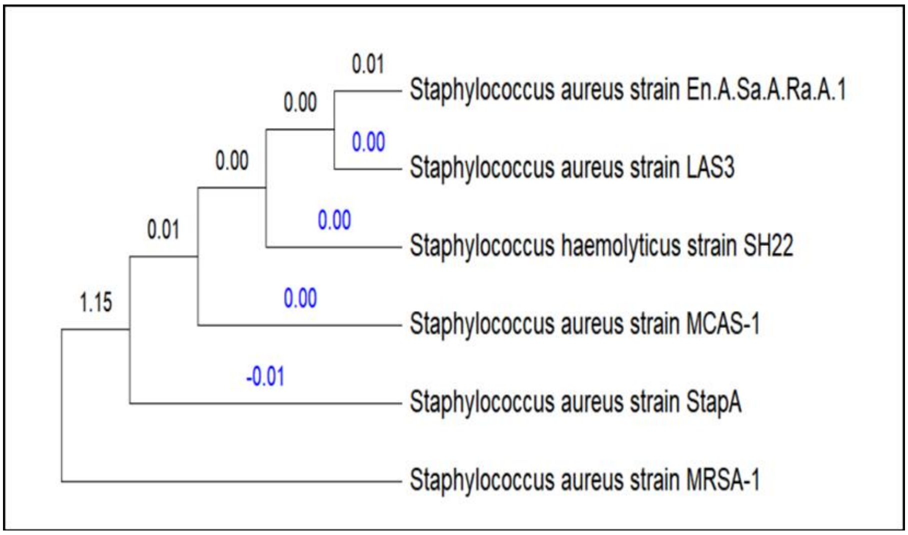

Figure 7. Phylogenetic tree of *S. aureus* strain En.A.Sa.A.Ra.A.1 showing evolutionary relationships with reference strains

DNA cleavage activity: The DNA cleavage potential of the extracted volatile oil versus the pathogenic *S. aureus* strain was evaluated by agarose gel electrophoresis. Three concentrations of the oil (100%, 50%, and 25% v/v) were examined. The control lanes, containing bacterial genomic DNA with and without DMSO, exhibited clear and intact DNA bands, affirming that the solvent did not affect DNA integrity. In contrast, all lanes given treatment with the volatile oil showed a complete absence of DNA bands, denoting extensive degradation of the bacterial genomic DNA (Figure 8).

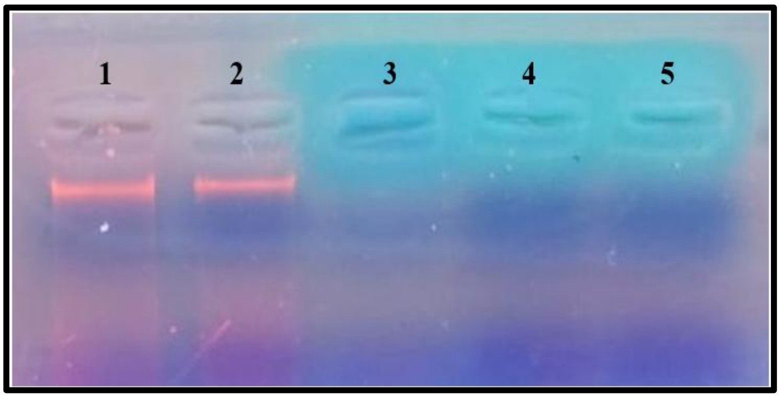

Figure 8. DNA cleavage activity of the extracted volatile oil versus *S. aureus*. Lanes 1 and 2: control DNA with and without DMSO, respectively. Lanes 3–5: DNA given treatment with the volatile oil at 100%, 50%, and 25% (v/v)

Physicochemical attributes of major volatile oil components: GC-MS analysis disclosed that six great compounds accounted for over 90% of the total volatile oil composition (Figure 9). The predicted physicochemical attributes of these compounds were analyzed applying the SwissADME web tool, centralizing on molecular weight, consensus LogP, hydrogen bond donors (HBD), hydrogen bond acceptors (HBA), and topological polar surface area (TPSA). A radar chart visualization of these parameters is presented in Figure 10, and detailed numerical values are summarized in Table 3.

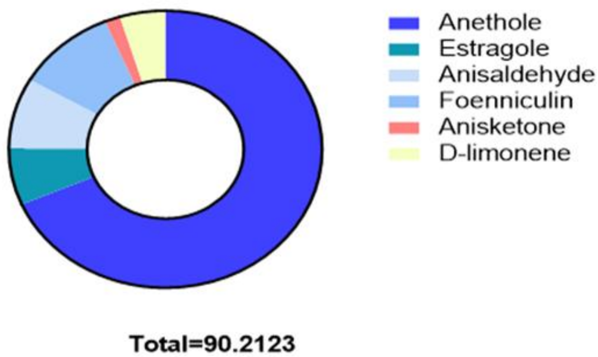

Figure 9. Compositional analysis of the extracted volatile oil emphasizing the six great compounds

Table 3. Predicted physicochemical attributes of the six major volatile oil compounds

Compound	Molecular Weight	Consensus LogP	HBD	HBA	TPSA (Å²)
Anethole	148.20 g/mol	2.79	0	1	9.23
Foeniculin (1-(3-Methyl-2-butenoxy)-4-(1-propenyl) benzene)	202.29 g/mol	3.89	0	1	9.23
Anisaldehyde (Benzaldehyde, 4-methoxy-)	136.15 g/mol	1.61	0	2	26.30
Estragole	148.20 g/mol	2.78	0	1	9.23
Anisketone (2-Propanone, 1-(4-methoxyphenyl)-)	164.20 g/mol	1.94	0	2	26.30
D-Limonene	136.23 g/mol	3.37	0	0	0.00

Discussion

Volatile oils are between the most momentous indigenous products derived from plants and have been applied in medicine since ancient times. Star anise (*Illicium verum*) is a medicinal plant distinguished by its highly aromatic volatile oil, which is also a well-known culinary spice. Beyond its aromatic qualities, this oil is medicinally meaningful due to the presence of unique bioactive compounds (Vella et al., 2020). Hydrodistillation applying a Clevenger apparatus supplies a straightforward and effective method for extracting volatile oils. This approach is preferred because it avoids the use of harsh, potentially toxic organic solvents that could contaminate the final product and pose environmental hazards. Furthermore, the method minimizes thermal degradation by collecting the volatile oil as it vaporizes and keeping it on the water surface.

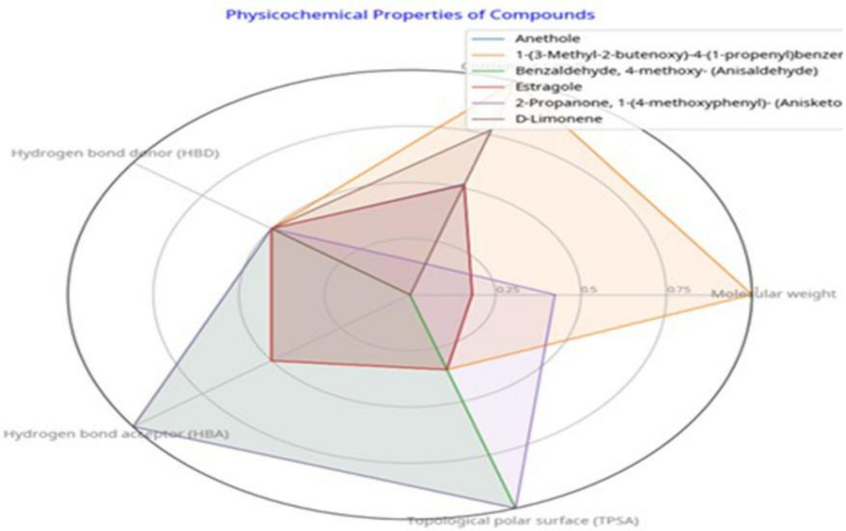

Figure 10. Radar chart depicting the predicted physicochemical attributes of the six major volatile oil compounds

This process protects heat-sensitive components from extended exposure to high temperatures, thereby preserving their constructional integrity and bioactivity. These factors likely participated to the retention of the oil's meaningful biological activities, as evidenced by its antioxidant capacity and DNA-cleavage reactions (Aziz et al., 2018). Gas chromatography-mass spectrometry (GC-MS) is a powerful analytical tool for volatile oils due to its capability to separate, identify, and quantify individual components. The GC-MS technique is essential in determining the perception the chemical composition of compound oils and associating these compounds with biological activity (Shaikh, 2021). According to the GC-MS data (Figures 1 & 2, Table 1), anethole is the most predominant and biologically demanding compound found in star anise volatile oil. Previous reported studies have underscored anethole as a major contributing factor to the pharmacological effects of the oil. Other significantly identified constituents include estragole, limonene, and several monoterpenes and various minor components such as anisaldehyde (Zhang et al., 2024). In general, the GC-MS analysis concluded that phenylpropanoids are the primary chemical constituents of the oil, and anethole is the primary bioactive compound. The considerable antioxidant activity of the bioactive compounds is identified in their electron-relaying role as a consequence of the transfer process mitigating damage from oxidative stress (Sharafan et al., 2022). The electron-rich aromatic systems characteristic of phenylpropanoids enable electron donation to molybdenum (VI) ions (Mo^{6+}), which is fundamental to the phosphomolybdenum assay methodology (Raposo et al., 2024; Jafri et al., 2017). The 2,2-diphenyl-1-picrylhydrazyl radical scavenging assay was also performed in a hydrogen atom transfer (HAT) mechanism and yielded insights into the testament to the antioxidant activity of individual compounds. Thus, the methoxy Group (OCH_3) in anethole and aliphatic double bond in its propyl side chain enable hydrogen atom abstraction from the allylic. Radical scavenging is achieved through methyl group ($-CH=CHCH_3$), proton transfer. A consequence is stabilized by resonance delocalization over the aromatic ring and conjugated alkene, and single-electron transfer is achieved to neutralize radicals due to the benzene ring's electron-rich nature are also contributing to the ability (Figure 3). Furthermore, the volatile oil exhibited excellent antioxidant activity in the Ferric reducing antioxidant power assay, which reflects its ability to donate electrons and reduce $Fe^{3+}$to Fe^{2+}. A higher FRAP value is associated with more robust antioxidant potential resulting from electron-richπ-systems related to phenylpropanoids' capacity to strip iron (Figure 4). The results are consistent with this expectation (Alam et in its propyl side chain facilitate hydrogen atom abstraction from the allylic methyl group ($-CH=CHCH_3$), effectively scavenging DPPH radicals via proton transfer. The consequence radical is stabilized via resonance delocalization across the aromatic ring and conjugated alkene, while the electron-rich nature of the benzene ring further promotes single-electron transfer to neutralize radicals (Figure 3). The volatile oil also revealed remarkable antioxidant effectiveness in the Ferric Reducing Antioxidant Power (FRAP) assay (Figure 4), reflecting its capacity to donate electrons and reduce ferric (Fe^{3+}) to ferrous (Fe^{2+}) ions. A higher

FRAP value illustrates a stronger antioxidant potential, which is commonly seen in phenylpropanoids due to their electron-rich π-systems facilitating iron depletion (Alam et al., 2013; Shahat et al., 2011) In conclusion, the outcomes presented together demonstrate powerful antioxidant activity of star anise volatile oil through both hydrogen atom transfer and single electron transfer mechanisms. This reaffirms cytoprotection against oxidative damage. Diabetic foot ulcers present a common, devastating, and distressful element of diabetes with the majority developing infection that significantly increase morbidity and mortality. *Staphylococcus aureus* has been the most common species extracted due to its virulent factors, and increasing resistance to antibiotics complicates and decreases advances in treatment (Dunyach-Remy et al., 2016). The 16S-rRNA gene has been widely recognized as the foremost molecule for bacterial phylogeny and taxonomy (Bady et al.,2021) (Figure 5) because of its universal presence in all bacterial species and highly conserved function throughout evolutionary time (Janda & Abbott, 2007). It is important to note that phylogenetic analysis of 16S rRNA sequences indicated different grades of genetic relatedness among the *Staphylococcus* strains. Thus, for instance, in the majority of *S.aureus* strains, the branch lengths are either absent or short (Figures 6 & 7, Table 2) En.A.Sa.A.1, LAS3, MCAS-1, which can be easily interpreted as the high-percentage genetic similarity of these strains in this gene region, which is typical for strains of the same species. Furthermore, DNA cleavage reactions showed that the volatile oil is very effective in breaking down the bacterial DNA. Thus, as it can be seen in Figure 8, after the bands were gone from the agarose gel, it turned out that the genomic DNA of the bacterium had been completely destroyed, which clearly indicates the pronounced genotoxic activity of the oil. It can be caused by the high-molecular physicochemical properties of its components. Thus, considering Table 3and Figure 10, almost 90% of the compounds in the oil are hydrophobic, and the molecular weight of the most significant components in the oil is low. This allows them to enter the bacterial cell from its first barrier, the peptidoglycan layer, and easily pass across the plasma membrane. Further, inside the cell, the oil components break the DNA, and synergistic interaction results in the enhancement of this effect, when the power of joint action exceeds the sum of the power of the effects of compound strains (Chouhan et al., 2017). These results propose that star anise volatile oil may serve as a hopeful alternative to conventional antibiotics, exclusively in the context of rising drug resistance. Unlike many conventional antibiotics that target particular bacterial structures or processes, this oil exerts a dual mechanism: it acts as a potent antioxidant while directly damaging bacterial DNA. The low molecular weight and high lipophilicity of its great constituents facilitate cellular penetration and DNA disruption, reducing the likelihood of resistance expansion. Additionally, as an indigenous product with a long history of medicinal use, star anise may propose a progressive safety profile in comparison to synthetic antibiotics, which often create adverse reactions and environmental concerns (Khwaza & Aderibigbe, 2025; Sakkas & Papadopoulou, 2017). In this investigation, locally sourced star anise volatile oil revealed meaningful dual-action antibacterial potential. GC-MS affirmed anethole as the predominant compound. The oil exhibited strong antioxidant activity via both electron and hydrogen atom transfer mechanisms, and DNA cleavage assays supplied clear evidence of complete genomic DNA degradation in pathogenic *S. aureus* strains. The combined genotoxic and the oil's potential as an indigenous therapeutic agent versus antibiotic-resistant pathogens, exclusively those implicated in diabetic foot infections.

Conclusion: This investigation affirms that star anise volatile oil exhibits meaningful antibacterial activity versus *Staphylococcus aureus*, which can be attributed to both its antioxidant attributes and the presence of active compounds, exclusively anethole. Anethole's low molecular weight and lipophilicity likely enable it to penetrate bacterial cell walls and membranes, leading to degradation of genetic material. These results illustrate that star anise volatile oil is a hopeful indigenous agent for the expansion of novel antimicrobial strategies, especially in combating antibiotic-resistant infections.

Author contributions

Sabaa Ali Mohammed Al-Fadal participated to the investigation design, carried out the DNA cleavage experiments, analyzed the outcomes, and drafted the manuscript. Rafeef Amer Abdul-Jabar was responsible for conducting the antioxidant analyses and interpreting the related data. Enas A. Bady extracted and recognized the bacterial strains applied in the investigation. All authors reviewed the final manuscript, approved its submission, and agreed to be accountable for all aspects of the work, ensuring the accuracy and integrity of the study.

Data availability statement

The datasets generated and/or analyzed through the current investigation are not publicly available due to institutional restrictions but are available from the corresponding author upon reasonable request. All data supporting the results of this study have been accurately displayed within the manuscript and related figures or tables.

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Ethical considerations

This investigation did not involve human participants or animal experimentation. All laboratory procedures were managed in accordance with institutional biosafety regulations, ethical research standards, and Good Laboratory Practice (GLP) guidelines established by the College of Pharmacy, University of Basrah.

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the conception, conduct, authorship, or publication of this study. The authors also affirm that there were no personal, professional, or financial relationships that could have impressed the outcomes or interpretations showed in this article.

References

Abers, M., Schroeder, S., Goelz, L., Sulser, A., St. Rose, T., Puchalski, K., & Langland, J. (2021). Antimicrobial activity of the volatile substances from essential oils. *BMC Complementary Medicine and Therapies, 21*(1), Article 124. https://doi.org/10.1186/s12906-021-03285-3

Alam, M. N., Bristi, N. J., & Rafiquzzaman, M. (2013). Review on in vivo and in vitro methods evaluation of antioxidant activity. *Saudi Pharmaceutical Journal, 21*(2), 143–152. https://doi.org/10.1016/j.jsps.2012.05.002

Aziz, Z. A. A., Ahmad, A., Setapar, S. H. M., Karakucuk, A., Azim, M. M., Lokhat, D., Rafatullah, M., Ganash, M., Kamal, M. A., & Ashraf, G. M. (2018). Essential oils: Extraction techniques, pharmaceutical and therapeutic potential—A review. *Current Drug Metabolism, 19*(13), 1100–1110. https://doi.org/10.2174/1389200219666180723144850

Bady, E. A., Sabaa, A. M., Al-Fadal, R. A., Abdul-Jabar, & Al-Rubeai, D. B. (2021). Identification of novel bacteria by using 16S rRNA from clinical and soil samples. *Indian Journal of Forensic Medicine & Toxicology, 15*(2), 4252–4259. https://doi.org/10.37506/ijfmt.v15i2.15038

Chouhan, S., Singh, K., & Gautam, S. (2017). Antimicrobial activity of some essential oils—Present status and future perspectives. *Medicines, 4*(3), Article 58. https://doi.org/10.3390/medicines4030058

Dong, Z. Y., Manik, P. N., Rao, M. X., Hong, F. W., Wael, N. H., Wei, C., & Li, W. J. (2017). Antibacterial activity of silver nanoparticles against *Staphylococcus warneri* synthesized using endophytic bacteria by photo-irradiation. *Frontiers in Microbiology, 8*, Article 1090. https://doi.org/10.3389/fmicb.2017.01090

Dunyach-Rémy, C., Nse, C., Sotto, A., & Lavigne, J.-P. (2016). *Staphylococcus aureus* toxins and diabetic foot ulcers: Role in pathogenesis and interest in diagnosis. *Toxins, 8*(7), Article 209. https://doi.org/10.3390/toxins8070209

Fagbemi, K. U., Adeyemi, D. A., & Oladipo, O. O. (2021). Soxhlet extraction versus hydrodistillation using the Clevenger apparatus: A comparative study on the extraction of a volatile compound from *Tamarindus indica* seeds. *The Scientific World Journal, 2021*, Article 5961586. https://doi.org/10.1155/2021/5961586

Felsenstein, J. (2003). *Inferring phylogenies* (2nd ed.). Sinauer Associates.

Heravi, F. S., Zakrzhevska, M., Vickery, K., Graves, D. A., & Hu, H. (2019). Bacterial diversity of diabetic foot ulcers: Current status and future prospectives. *Journal of Clinical Medicine, 8*(11), Article 1935. https://doi.org/10.3390/jcm8111935

Jafri, L., Saleem, S., Ihsan-ul-Haq, N. U., & Mirza, B. (2017). In vitro assessment of antioxidant potential and determination of polyphenolic compounds of *Hedera nepalensis* K. Koch. *Arabian Journal of Chemistry, 10*, S3699–S3706. https://doi.org/10.1016/j.arabjc.2014.05.002

Janda, J. M., & Abbott, S. L. (2007). 16S rRNA gene sequencing for bacterial identification in the diagnostic laboratory: Pluses, perils, and pitfalls. *Journal of Clinical Microbiology, 45*(9), 2761–2764. https://doi.org/10.1128/JCM.01228-07

Khwaza, V., & Oyedeji, B. A. (2025). Antibacterial activity of selected essential oil components and their derivatives: A review. *Antibiotics, 14*(1), Article 68. https://doi.org/10.3390/antibiotics14010068

Moghaddam, H. H., Jalil, A. A., Shokouh, F., & Jafari, S. K. (2023). Influence of climatic factors on essential oil content and composition of 20 populations of *Nepeta binaludensis* Jamzad from Iran. *Applied Biological Chemistry, 66*, Article 3. https://doi.org/10.1186/s13765-022-00750-6

Mohamed, A. A., & Alotaibi, B. M. (2023). Essential oils of some medicinal plants and their biological activities: A mini review. *Journal of Umm Al-Qura University for Applied Sciences, 9*(1), 40–49. https://doi.org/10.1007/s43994-022-00018-1

Noumi, E., Ahmad, I., Patel, H., Mkandawire, A., Bouali, N., Hfaiedh, N., Boughalleb, N., Alabbosh, K. F. A. K., Ciofalo, L., Passantino, F., Snoussi, M., & De Feo, V. (2023). *Illicium verum* L. (star anise) essential oil: GC/MS profile, molecular docking study, *in silico* ADME profiling, quorum sensing, and biofilm-inhibiting effect on foodborne bacteria. *Molecules, 28*(23), Article 7691. https://doi.org/10.3390/molecules28237691

Pavithra, K., Vadivukkarasi, S., & Jayakumar, V. (2015). Evaluation of free radical scavenging activity of various extracts of leaves from *Kedrostis foetidissima* (Jacq.) Cogn. *Food Science and Human Wellness, 4*(1), 42–46. https://doi.org/10.1016/j.fshw.2015.02.001

Photolo, M. M., Mavumengwana, V., Sisimayi, L., & Tlou, M. G. (2020). Antimicrobial and antioxidant properties of a bacterial endophyte, *Methylobacterium radiotolerans* MAMP 4754, isolated from *Combretum erythrophyllum* seeds. *International Journal of Microbiology, 2020*, Article 9483670. https://doi.org/10.1155/2020/9483670

Raposo, A., Delgado, R., Zappia, R., Singh, N., Adeola, O., Rodriguez-Bernaldo de Quirós, B., Chaves, C., Sharifi-Rad, J., Bang, H. R., Han, H., & Callegari, D. (2024). Anethole in cancer therapy: Mechanisms, synergistic potential, and clinical challenges. *Biomedicine & Pharmacotherapy, 180*, Article 117449. https://doi.org/10.1016/j.biopha.2024.117449

Sakkas, H., & Papadopoulou, C. (2017). Antimicrobial activity of basil, oregano, and thyme essential oils. *Journal of Microbiology and Biotechnology, 27*(3), 429–438. https://doi.org/10.4014/jmb.1608.08024

Salar, R. K., Singhal, P., & Pandey, S. S. (2015). In vitro antioxidant and free radical scavenging activities of stem extract of *Euphorbia trigona* Miller. *TANG [Humanitas Medicine], 5*(2), e14. https://doi.org/10.5667/tang.2015.0004

Shaaban, H. A. E., El-Ghorab, A. H., & Shibamoto, T. (2012). Bioactivity of essential oils and their volatile aroma components: Review. *Journal of Essential Oil Research, 24*(2), 203–212. https://doi.org/10.1080/10412905.2012.659528

Shahat, A. A., Ibrahim, A. Y., Hendawy, S. F., Omer, E. A., Hammouda, F. M., Abdel-Rahman, F. H., & Saleh, M. A. (2011). Chemical composition, antimicrobial and antioxidant activities of essential oils from organically cultivated fennel cultivars. *Molecules, 16*(2), 1366–1377. https://doi.org/10.3390/molecules16021366

Sharafan, M., Jakubczyk, K., Zięba, E., Kiersnowska, P., Krupa, R., Baraniak, E., & Skoczypiec, A. (2022). *Illicium verum* (star anise) and trans-anethole as valuable raw materials for medicinal and cosmetic applications. *Molecules, 27*(3), Article 650. https://doi.org/10.3390/molecules27030650

Vecchio, M. D., Amato, G., Gulati, C. M., & Loizzo, G. (2016). *Pimpinella anisum* and *Illicium verum*: The multifaceted role of anise plants. *The Open Agriculture Journal, 10*(1), 81–86. https://doi.org/10.2174/1874331501610010081

Vella, F. M., Crupi, R., Cirmi, S., Pergolizzi, G., & Loizzo, G. R. (2020). Chemometric screening of fourteen essential oils for their composition and biological properties. *Molecules, 25*(21), Article 5126. https://doi.org/10.3390/molecules25215126

Wong, Y. C., Lee, P. P., & Wan Nurdiyana, W. A. (2014). Extraction and antioxidative activity of essential oil from star anise (*Illicium verum*). *Oriental Journal of Chemistry, 30*(3), 1159–1171. https://doi.org/10.13005/ojc/300329

Zhang, G., Zheng, M., Pan, Y., Li, N., Bu, C., Ren, C., Guo, M., Yang, W., & Guo, T. (2024). Revealing the potential of star anise essential oil: Comparative analysis and optimization of innovative extraction methods for enhanced yield, aroma characteristics, chemical composition, and biological activities. *Food Science & Nutrition, 12*(11), 9540–9554. https://doi.org/10.1002/fsn3.4508

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نقش دوگانه روغن فرّار بادیان ستاره‌ای: بررسی اثرات آنتی‌اکسیدانی و تخریب DNA علیه *Staphylococcus aureus*

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چکیده

هدف: افزایش تهدید مقاومت آنتی‌بیوتیکی، به‌ویژه در *Staphylococcus aureus*، نیازمند گسترش رویکردهای درمانی نوین است. هدف از این پژوهش، بررسی پتانسیل عملکردی دوگانه روغن فرّار بادیان ستاره‌ای (*Illicium verum*) از نظر اثرات آنتی‌اکسیدانی و توانایی تخریب DNA بود. مطالعات پیشین نشان داده‌اند که بادیان ستاره‌ای به‌طور سنتی به‌عنوان ادویه غذایی و در طب عامیانه برای درمان سرفه و تسکین درد استفاده می‌شود، اما مکانیسم دقیق فعالیت ضدباکتریایی روغن اسانسی آن همچنان ناشناخته است.

مواد و روش‌ها: برای انجام آزمون‌های تحلیلی و زیستی از کروماتوگرافی گازی–طیف‌سنجی جرمی (GC-MS)، ظرفیت کل آنتی‌اکسیدانی، آزمون مهار رادیکال DPPH، آزمون FRAP و آزمون تخریب DNA استفاده شد. ایزوله‌های باکتریایی از زخم پای دیابتی به‌دست آمده، شناسایی و با استفاده از تعیین توالی ژن 16S rRNA توصیف ژنتیکی شدند، سپس تحلیل جهش بر روی آن‌ها انجام گردید. نرم‌افزار SwissADME برای تحلیل ویژگی‌های فیزیکوشیمیایی از جمله وزن مولکولی، LogP، تعداد دهنده‌ها و گیرنده‌های پیوند هیدروژنی و مساحت قطبی توپولوژیکی (TPSA) استفاده شد.

نتایج: تحلیل GC-MS ترکیب شیمیایی غالب آنتول را با مقادیر قابل‌توجهی از استراگول، لیمونن و آنیس‌آلدهید نشان داد. آزمون DPPH فعالیت مؤثر مهار رادیکال آزاد را با IC_{50} برابر ۷/۲ درصد (v/v) در مقایسه با ۳/۵ درصد (v/v) برای ویتامین E نشان داد. تحلیل FRAP نیز فعالیت آنتی‌اکسیدانی وابسته به دوز را تأیید کرد. در این مطالعه یک ایزوله باکتریایی جدید شناسایی شد که به‌عنوان سویه جدید *S. aureus* معرفی و با شماره دسترسی PX068377.1 در پایگاه GenBank ثبت گردید. فقدان باند DNAدر الکتروفورز پس از آزمون تخریب DNA، تخریب ژنومی قابل‌توجهی را نشان داد که می‌تواند ناشی از اثرات ژنوتوکسیک قوی ترکیبات با وزن مولکولی پایین و آب‌گریزی بالای روغن فرّار باشد؛ ویژگی‌هایی که نفوذ سریع به غشا و در نتیجه تخریب اسید نوکلئیک آسیب‌دیده را تسهیل می‌کنند.

نتیجه‌گیری: با توجه به خواص آنتی‌اکسیدانی و ژنوتوکسیک قوی روغن اسانسی بادیان ستاره‌ای که در این مطالعه نشان داده شد، این ماده می‌تواند به‌عنوان یک عامل ضد میکروبی طبیعی و بومی بالقوه، به‌ویژه علیه باکتری‌های مقاوم به آنتی‌بیوتیک معرفی گردد.

کلمات کلیدی: آنتول، زخم پای دیابتی، GC–MS، *Illicium verum*، *Staphylococcus aureus*

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