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ORIGINAL RESEARCH ARTICLE

Chemical Profile, Antioxidant Potential, and Antibacterial Activity of Heracleum persicum Essential Oil against Staphylococcus aureus and Escherichia coli

Amirmohammad Hajati[1], Edris Mahdavi Fikjvar[2], Maedeh Mohammadi Jonaghani[3], Parisa Satvat[3], Nooshin Amini[4]

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Abstract

Background The medicinal plant Heracleum persicum has attracted attention due to its bioactive compounds and antimicrobial properties. This study aimed to identify the constituents of essential oil from dried H. persicum fruits and evaluate its antibacterial and antioxidant activities.

Methods Essential oil was extracted from dried fruits using a Clevenger-type distillation apparatus. The components were identified by gas chromatography–mass spectrometry. Total phenolic and flavonoid contents were determined. Antibacterial activity against Staphylococcus aureus and Escherichia coli was assessed using the disk diffusion method and by determining the minimum inhibitory concentration. Antioxidant activity was measured using the DPPH radical scavenging assay.

Results Thirty-one compounds were identified, with n-hexyl butyrate (49.98%) and octyl acetate (15.39%) being the most abundant. The essential oil contained high levels of phenolics (108.25 ± 0.1 mg/g) and flavonoids (21.29 ± 0.1 mg/g). Its antioxidant activity was lower than BHT (IC50 = 1443.92 µg/mL). Significant antibacterial effects were observed against Staphylococcus aureus (MIC = 0.2 mg/mL) and, to a lesser extent, Escherichia coli (MIC = 0.5 mg/mL), whereas activity against other tested bacteria was weaker (MIC > 16 mg/mL).

Conclusion The essential oil of H. persicum fruits contains bioactive compounds and exhibits notable antibacterial activity, particularly against Staphylococcus aureus. Its antioxidant activity was lower than the synthetic antioxidant BHT, and further studies are required to assess safety and efficacy in in vivo conditions.

Keywords Antibacterial agent, Escherichia coli, Essential oil, Heracleum persicum, Staphylococcus aureus

✉ Edris Mahdavi Fikjvar
ias.intl.scientists@gmail.com

1. School of Pharmacy, Guilan University of Medical Sciences, Rasht, Iran
2. Medical Biotechnology Research Centre, School of Paramedicine, Guilan University of Medical Sciences, Guilan, Iran
3. Department of Cell and Molecular Biology, Faculty of Science and Advanced Biological Technologies, Tehran East Branch, Islamic Azad University, Tehran, Iran
4. Member of the Scientific Committee and Management, Global Network for Research, Education, and Events (GREEN), Tehran Representative Office, Iran

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1 Introduction

Heracleum persicum, a medicinal plant native to Iran and belonging to the Apiaceae family, has traditionally been used as both a spice and a therapeutic agent in traditional medicine. This plant predominantly grows in the mountainous regions of northern and western Iran, and various parts, including seeds and leaves, are utilized for the extraction of bioactive compounds.[1] Studies have shown that its essential oil is rich in constituents such as coumarins, flavonoids, and volatile oils, which exhibit multiple properties, including antimicrobial, antioxidant, anti-inflammatory, and gastroprotective activities. These characteristics have drawn attention to Heracleum persicum for the prevention and alleviation of conditions such as gastrointestinal infections, inflammatory disorders, pain relief, wound healing, the inhibition of pathogenic bacteria, and even the reduction of risk for certain cancers, including gastric cancer.[2,3]

A gram-positive, coccoid, and clustered bacterium naturally inhabits the skin, nose, and respiratory tract of humans and animals. It is considered part of the normal body flora but can become an opportunistic pathogen under specific conditions such as immunosuppression, skin injuries, or surgical procedures. This bacterium can cause various diseases, including skin infections, wounds, sepsis, pneumonia, endocarditis, and food poisoning. The high resistance of some strains, particularly methicillin-resistant strains, poses significant challenges for treatment. Currently, the management of infections caused by this bacterium depends on the type of infection and may include antibiotics such as vancomycin, clindamycin, or newer agents. However, the increasing prevalence of drug resistance has heightened interest in herbal medicines and natural compounds, including plant essential oils, as alternative or complementary therapeutic options.[4-6]

Gram-negative, rod-shaped bacteria belonging to the family Enterobacteriaceae naturally inhabit the intestines of humans and many warm-blooded animals. As part of the normal gut flora, these microorganisms play a role in food digestion and the synthesis of certain vitamins, including vitamin K, with most strains being non-pathogenic and harmless. However, specific strains such as Enterohemorrhagic Escherichia coli (EHEC), Enteropathogenic Escherichia coli (EPEC), and Enterotoxigenic Escherichia coli (ETEC) can be pathogenic, causing gastrointestinal infections, diarrhea, urinary tract infections, and, in severe cases, septicemia. This bacterium is also used as a key microbial indicator in assessing microbial contamination of water and food. Furthermore, it serves as a major host in biotechnological applications and is widely employed in gene cloning and recombinant protein production.[7,8]

In recent years, Heracleum persicum has attracted considerable attention due to its bioactive compounds and antimicrobial properties. Traditionally, this plant has been used as an anthelmintic, carminative, appetite stimulant, and diuretic.[9] Various studies have demonstrated that Heracleum persicum essential oil exhibits significant inhibitory effects against gram-positive bacteria, particularly Staphylococcus species.[9,10] Although fewer studies have investigated its effects on gram-negative bacteria such as Escherichia coli, some research suggests that plants with similar properties, such as Calendula officinalis, may also affect these bacteria, although the effect is generally weaker or requires higher essential oil concentrations.[11-13]

Studies have shown that different plant essential oils exhibit varying antibacterial activities against these two bacterial groups. For instance, ethanol extracts of Piper betle leaves showed significant antibacterial activity against Staphylococcus aureus, whereas Cassia fistula essential oil primarily exhibited bacteriostatic properties.[14] Additionally, other studies indicated that certain essential oils, such as those from Cremaspora triflora and Maesa lanceolata, displayed high antibacterial activity against Escherichia coli.[15] In contrast, research on the essential oil from Artocarpus heterophyllus seeds reported no effect against drug-resistant Escherichia coli.[16] These findings suggest that the antibacterial activity of plant essential oils may vary depending on the plant species, extraction method, and the target bacterial strain. Despite extensive evidence regarding the antimicrobial properties of Heracleum persicum essential oil against gram-positive bacteria, sufficient information is lacking on its effects against gram-negative bacteria, particularly resistant strains. Moreover, the considerable variation in antibacterial activity among different plant essential oils necessitates a more comprehensive and precise investigation of the biochemical characteristics and bioactivity of the plant's active compounds. Therefore, the present study was conducted to evaluate the antibacterial activity of Heracleum persicum essential oil against both gram-positive and gram-negative bacteria, aiming to address this gap in scientific knowledge and to explore novel applications in herbal medicine, alternative therapies, and the control of antibiotic-resistant infections. The results of this research may provide a foundation for the development of natural pharmaceutical products with effective antibacterial properties and reduce reliance on chemical drugs, which is of significant importance for public health improvement and the management of drug resistance.

2 Methods

In this experimental–laboratory study, all procedures were conducted in accordance with the ethical principles of biomedical research and were approved by the Ethics

Committee of the International Association of Scientists (IAS) with the Ethical Code IASECA.PEM.2506.2024. Throughout all stages, biosafety guidelines, proper handling of chemical materials, and the storage of biological samples were strictly observed.

Collection and Drying of the Plant

The medicinal plant Heracleum persicum was collected in late June 2023 from an altitude of 1800 meters in the Javadredeh highland region, Ramsar, Mazandaran Province. The collected plant was dried at room temperature for two weeks, after which the leaves and fruits were separated. A herbarium specimen was prepared and, following identification, was deposited under the code 6451 at the Herbarium of the Research Center of Gilan Province.

Extraction of the Essential Oil of Heracleum persicum Fruits

Essential oil extraction was performed based on previous studies.[16,17] The dried plant samples were ground using an electric grinder, and 80 g of the plant material was placed into a Clonjer flask. Distilled water was added to fill two-thirds of the flask volume. The essential oil was extracted by heating the mixture to its boiling point and maintaining it for 3 hours. The obtained essential oil was dehydrated using anhydrous sodium sulfate and collected in glass vials. The essential oil was stored in a refrigerator, protected from light, before analysis and throughout the various stages of the experiments.

Analysis of the Essential Oil Components of Heracleum persicum Fruit Using Gas Chromatography–Mass Spectrometry (GC–MS)

Initially, 1.2 mg of Heracleum persicum essential oil was diluted to 5 mL with n-hexane in a 5 mL flask, yielding a concentration of 240 ppm. Using a specialized syringe, 1 µL portion of this solution was withdrawn and introduced into the GC injector. As the initial concentration was insufficient for proper peak separation and identification, a new sample was prepared at a concentration of 1000 ppm. An aliquot (1 µL) of this solution was injected into a GC–MS system (Agilent Technologies, Model 5977B MSD-GC, USA) equipped with a DB-1 capillary column (non-polar, 60 m × 0.25 mm internal diameter, 0.25 µm film thickness). The oven temperature per minute. The ionization source was maintained at 230°C, and the injection port temperature was set at 250°C. Helium was used as the carrier gas at a flow rate of 1 mL/min.

The instrument analyzed the essential oil components, and the identification of each constituent was achieved by comparing the mass spectra with those in the GC/MS library. The relative percentage of each component was calculated based on the area under the corresponding peaks in the chromatogram.

Determination of the Antioxidant Activity of Heracleum persicum Essential Oil

The total phenolic content of the essential oil was determined using a colorimetric phenol method based on the phosphomolybdenum acid reaction, as described in previous studies.[14,15] Results were expressed as milligrams of gallic acid equivalents per gram of essential oil. Total flavonoid content was measured using the aluminum chloride colorimetric method and reported as milligrams of rutin equivalents per gram of essential oil.

To evaluate antioxidant activity, the DPPH free radical scavenging assay was employed. In this assay, various concentrations of the essential oil were reacted with a DPPH solution, and the decrease in absorbance at a specific wavelength was measured. The half-maximal inhibitory concentration (IC_{50}), representing the concentration required to inhibit 50% of DPPH free radicals, was calculated. The antioxidant activity of the essential oil was compared with the synthetic standard BHT to assess its relative potency. All measurements were performed in triplicate, and results were reported as mean ± standard deviation.

The antioxidant activity of Heracleum persicum fruit essential oil was assessed using the DPPH radical scavenging assay. The percentage of DPPH radical inhibition was calculated using the following formula:

DPPH Radical Scavenging Activity (%) = (Acontrol− Asampl) / Acontrol ×100" , where Acontrol is absorbance of the DPPH solution without the sample (only solvent and DPPH), and Asample is absorbance of the DPPH solution with the essential oil sample. This formula represents the extent of DPPH free radical inhibition by the sample, and the result is expressed as a percentage.

Preparation of Microbial Samples and Assessment of Antibacterial Activity

Standard strains of Staphylococcus aureus (ATCC 25923) and Escherichia coli (ATCC 25922) were obtained from the microbial bank of the Pasteur Institute. The strains were initially cultured in nutrient broth and, after 24 hours of incubation at 37°C, transferred to nutrient agar for purification. Pure colonies were then used to prepare bacterial suspensions in physiological saline at a concentration equivalent to 0.5 McFarland standard (≈ 1.5×10^8 CFU/mL).

To evaluate the antibacterial activity of the essential oil, the disk diffusion method on Mueller–Hinton agar was employed, following previous studies.[18,19] First, the surface of the culture medium was uniformly inoculated with a sterile bacterial suspension. Sterile paper disks (6 mm in diameter) were then impregnated with 20 µL of each essential oil concentration and placed at regular intervals on the agar surface. The plates were incubated at 37°C for 24 hours. After incubation, the diameter of the inhibition zones around each disk was measured

using a digital caliper with 0.01 mm precision.

To determine the minimum inhibitory concentration (MIC), the microdilution method in 96-well plates was used. The essential oil was serially diluted, and 100 µL of bacterial suspension was added to each well. The plates were incubated for 24 hours, after which 10 µL of triphenyl tetrazolium chloride (TTC) reagent was added for colorimetric assessment. The absence of color change indicated no bacterial growth and was used to determine the MIC.

Data Analysis

Data were analyzed using SPSS version 25. To compare the mean diameters of inhibition zones among different groups, one-way analysis of variance (ANOVA) followed by Tukey's post hoc test was performed. A significance level of 0.05 was considered for all analyses.

3 Results

Composition of Heracleum persicum Fruit Essential Oil

The constituents of Heracleum persicum fruit essential oil were identified using gas chromatography–mass spectrometry (GC-MS). A total of 31 compounds were detected, accounting for 98.03% of the total essential oil composition. The major components were hexyl butyrate (49.98%) and octyl acetate (15.39%) (Table 1 and Figure 1).

The measurement error was estimated at ±2% for major compounds and ±5% for minor compounds. Since relative percentages were used in this study, the 49.98% content of n-hexyl butyrate was obtained directly by calculating the ratio of the peak area to the total peak areas (normalization) without the need for an external reference standard.

The findings in Table 1 indicate that various compounds belonging to the alcohol, ester, and aldehyde families were identified in the sample, with different MI/RMI values. The MI (Mass Intensity) or RMI (Relative Mass Intensity) represents the intensity or relative abundance of each compound in the sample, which may reflect the importance and contribution of each compound to the biological activity or properties of the sample. High MI/RMI values, such as those observed for 1-hexanol, butyl isobutyrate, and n-hexyl butyrate, indicate the prominent concentration or role of these compounds in the sample's function. The retention time indicates the duration over which the compound's effect persists and, in most cases, ranges from 7 to 25 minutes, suggesting the relative stability of the compounds. The percentage composition reflects the contribution of each compound to the total sample, with compounds such as n-hexyl butyrate showing a high percentage (49.81%) and likely playing a more significant role in the chemical and functional properties of the sample.

Table 1 Chemical compounds, MI/RMI index, retention time, and relative abundance of each compound in the analyzed sample

Row	Compound name	MI/RMI	Inhibition time	Percentage composition
1	Hexanol-1	897.897	7.43	0.397
2	Isopropyl 2-methylbutyrate	875.875	8.08	0.865
3	Isopropyl isovalerate	897.897	8.35	0.797
4	1,3-Propanedial	911.759	8.94	0.110
5	Isobutyl isobutyrate	836.836	9.08	0.324
6	4-Methyl-2,3-pentanedial	751.706	9.54	0.282
7	Alpha-pinene	733.733	9.64	0.226
8	Butyl isobutyrate	947.947	10.51	1.851
9	2-Butenedioic acid	992.796	10.75	0.092
10	Boldione	846.846	11.19	0.194
11	Butyl butyrate	932.924	12.04	1.866
12	Octanal	886.886	12.23	0.824
13	Isobutyl isovalerate	802.759	12.40	0.153
14	n-Hexyl acetate	943.930	12.67	0.978
15	Beta-cymene	941.941	12.93	2.271
16	Butyl 2-methylbutyrate	938.934	13.62	1.673
17	Butyl isovalerate	862.862	13.77	1.104
18	Gamma-terpinene	942.942	14.11	2.602
19	1-Octanol	866.866	14.62	0.240
20	Linalool	662.643	15.54	0.283

21	n-Hexyl propionate	866.866	15.73	0.424
22	Hexyl isobutyrate	928.919	17.7	6.351
23	n-Hexyl butyrate	954.953	18.42	49.981
24	3-Octenyl acetate	887.887	18.60	1.828
25	Octyl acetate	963.963	18.99	15.394
26	Hexyl 2-methylbutyrate	946.944	19.69	4.085
27	Hexyl isovalerate	885.867	19.82	0.272
28	Octyl isobutyrate	878.878	22.67	0.572
29	Hexyl caproate	894.894	23.75	1.006
30	Octyl butyrate	872.872	23.84	0.467
31	Octyl 2-methylbutyrate	841.841	24.97	0.528

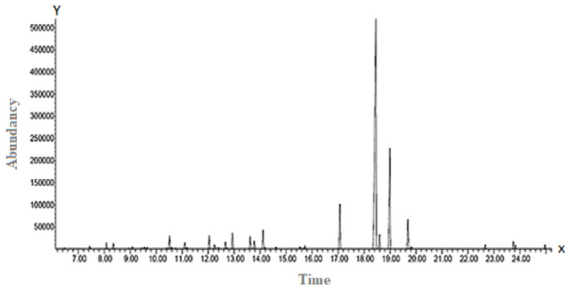

Figure 1 Gas chromatography–mass spectrometry (GC-MS) chromatogram of Golpar (Heracleum persicum) fruit essential oil. A total of 31 chemical compounds were identified, representing 98.03% of the total essential oil composition. The major constituents were hexyl butyrate (49.98%) and octyl acetate (15.39%)

MI/RMI represents the intensity or relative abundance of each compound in the sample, retention time (in minutes) indicates the duration over which the compound's effect is maintained, and the percentage composition reflects the relative contribution of each compound to the total sample.

The major compounds were hexyl butyrate (49.9%) and octyl acetate (15.39%), and statistical analysis indicated a significant difference between these two compounds and the other minor constituents ($p < 0.001$) (Figure 2).

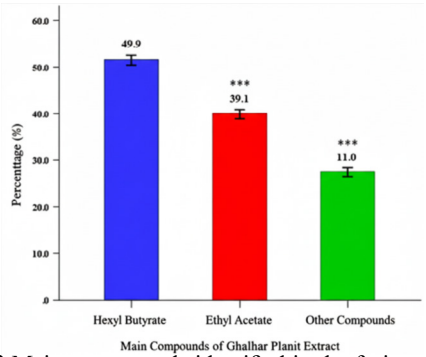

Figure 2 Major compounds identified in the fruit essential oil of Golpar (Heracleum persicum) based on GC-MS analysis. Values are presented as relative percentages. Error bars represent standard deviation. * indicates a significant difference compared to hexyl butyrate, and # indicates a significant difference compared to octyl acetate ($p < 0.001$: ***, ###).

Analysis of the chemical composition of Heracleum persicum fruit essential oil showed that the total phenolic content was 108.25 ± 0.1 mg gallic acid equivalents per gram, and the total flavonoid content was 21.29 ± 0.1 mg rutin equivalents per gram. The antioxidant activity of the essential oil, measured by the DPPH assay, was determined to be 1443.92 µg/mL. This activity was considerably lower than that of the synthetic antioxidant BHT, which had an IC_{50} value of 8.3 µg/mL (Table 2).

The pattern of DPPH free radical inhibition (%) by Heracleum persicum fruit essential oil at different concentrations, along with the IC_{50} value, is presented in Figure 3.

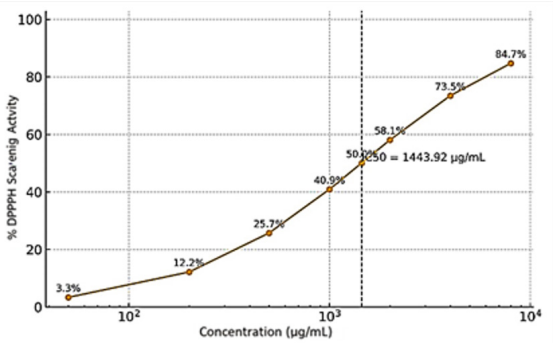

Figure 3 DPPH assay of Golpar (Heracleum persicum) essential oil and the corresponding IC_{50} value (≈ 1443.92 µg/mL)

Antibacterial Activity Results

The determination of the MIC of Heracleum persicum essential oil showed that the oil exhibits weak antibacterial activity against Escherichia coli, with an MIC exceeding 16 mg/mL. This indicates that high concentrations are required to inhibit the growth of this bacterium, reflecting the limited efficacy of the essential oil in this case. In contrast, the MIC of Heracleum persicum essential oil against Staphylococcus aureus was below 16 mg/mL, indicating relatively stronger antibacterial activity against this bacterial species. Therefore, it can be concluded that Heracleum persicum essential oil is more effective against Staphylococcus aureus than Escherichia

Table 2 Phenolic and flavonoid contents and antioxidant activity of Golpar (Heracleum persicum) essential oil. Total phenolic content is expressed as gallic acid equivalents, and total flavonoid content is expressed as rutin equivalents.

Antioxidant activity (μg/mL) (IC_{50})	Concentration of flavonoid Compounds (mg/g)	Concentration of phenolic compounds (mg/g)	Analytical method	Essential
1443.92	29.1/±21.0	25.1±108.0	UV-Vis Spectrophotometer	*Heracleum persicum*

coli (Figure 4).

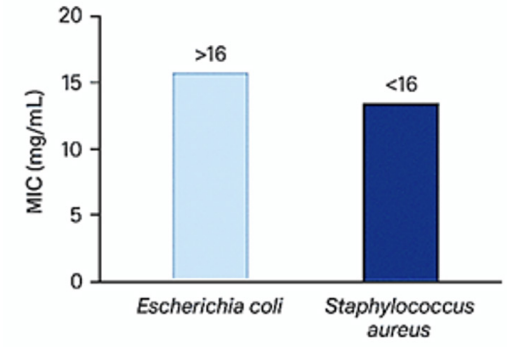

Figure 4 MIC of Heracleum persicum fruit essential oil against the bacterial strains Escherichia coli and Staphylococcus aureus

4 Discussion

The findings of this study demonstrated that the essential oil of Heracleum persicum fruit contains a considerable diversity of chemical compounds, primarily esters, alcohols, and aldehydes. The major constituents accounted for a large proportion of the total composition and likely play a key role in the functional properties of the oil. Analysis of phenolic and flavonoid contents also indicated the presence of bioactive compounds, although the antioxidant activity of the essential oil was weaker compared to synthetic antioxidants. Regarding antibacterial activity, Heracleum persicum essential oil was able to moderately inhibit the growth of the gram-positive bacterium Staphylococcus aureus, but showed limited inhibitory effect against the gram-negative bacterium Escherichia coli. These results suggest that Heracleum persicum essential oil has potential for targeting specific bacteria, although its efficacy depends on the type of microorganism and the dominant compounds present in the oil.

These findings are consistent with previous reports demonstrating notable antibacterial activity of Heracleum persicum essential oil, where inhibition zones against Staphylococcus aureus and Escherichia coli reached approximately 32 mm.[17] Additionally, low MIC values of the essential oil (10–20 ppm) against Acinetobacter baumannii have been reported.[18] GC-MS analysis has indicated that major constituents, such as hexyl butyrate, may play a key role in antibacterial activity through disruption of the bacterial cell membrane.[19] Moreover, it has been observed that Heracleum persicum essential oil is more effective against gram-positive bacteria, such as Listeria monocytogenes,[20] and its activity against Bacillus cereus has been independently confirmed.[21] Some studies have also suggested that coumarin compounds can complement antibacterial activity by inhibiting inflammation, a mechanism that may contribute to the antibacterial effects observed in the present study.[22]

Conversely, some studies have reported that Heracleum persicum essential oil, due to its high content of flavonoids and furanocoumarins, can exhibit antioxidant activity comparable to synthetic antioxidants under certain conditions.[23] Additionally, some of the plant's active compounds may display stronger antioxidant and antibacterial activities depending on environmental conditions and extraction methods.[24] In some studies, the MIC of the essential oil against gram-positive and gram-negative bacteria was reported to be much lower than the values obtained in the present study, indicating considerably stronger activity.[18] These differences are likely attributable to factors such as the extraction method, the plant part used, climatic conditions, genetic variation, or differences in bacterial strains.

Regarding the mechanism of action of Heracleum persicum essential oil, phenolic compounds such as coumarins and furanocoumarins, together with aliphatic esters like hexyl butyrate, appear to play a central role in its antibacterial properties. Phenolic compounds induce bacterial cell death by increasing cell membrane permeability and causing ion leakage.[22] Additionally, aliphatic esters disrupt DNA replication by inhibiting enzymes such as DNA gyrase and topoisomerase IV.[23] Furthermore, furanocoumarins, such as bergapten, may form covalent bonds with DNA under UV irradiation, disrupting nucleic acid synthesis. In combination with phenolic compounds, they exhibit a synergistic effect on bacterial cell membrane disruption.[24]

Overall, although the antioxidant activity of Heracleum persicum essential oil is limited compared to BHT, the presence of multiple antibacterial mechanisms and bioactive compounds indicates the plant's potential for scientific and research applications, without making claims regarding its high potential for the development of drugs or natural preservatives.

Despite providing valuable data on the antibacterial activity of Heracleum persicum essential oil, this study has several limitations that should be addressed in future research. First, the investigations focused only on two standard bacterial strains (Staphylococcus aureus and Escherichia coli), and antibiotic-resistant clinical strains were not evaluated. Second, the antibacterial mechanisms of the active compounds (such as hexyl butyrate and coumarins) were discussed solely based on theoretical considerations and previous studies, and require experimental validation through methods such as enzymatic assays and analysis of gene expression related to resistance. Third, the influence of environmental factors, such as geographical location and harvest season, on the chemical composition and biological activity of the essential oil was not assessed. Finally, evaluation of cytotoxicity and the potential application of this essential oil in pharmaceutical or food formulations necessitates additional in vivo and pharmacokinetic studies. Addressing these limitations could help optimize the use of Heracleum persicum essential oil as a natural antibacterial agent.

5 Conclusion

Based on the results of this study, the ethanolic essential oil of Heracleum persicum exhibits notable antibacterial activity, particularly against the Gram-positive bacterium Staphylococcus aureus, and can inhibit its growth at lower concentrations compared to Escherichia coli. Evaluation of the MIC indicated that the essential oil demonstrates stronger antibacterial activity, likely due to the higher concentration of phenolic and flavonoid compounds with antimicrobial and antioxidant properties. Although the antioxidant capacity of the essential oil was lower than that of the synthetic antioxidant BHT, the presence of active compounds such as hexyl butyrate and octyl acetate in the fruit essential oil may contribute to enhancing its antimicrobial properties. Overall, the findings of this study highlight the significant potential of Heracleum persicum as a natural source of antibacterial agents, with possible applications in the development of pharmaceutical products and natural preservatives, particularly in the food and hygiene industries. However, further studies on animal and human models are necessary to confirm the safety and efficacy of this essential oil in vivo.

Declarations

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Artificial Intelligence Disclosure
The authors declare that no generative artificial intelligence (AI) tools were used in the generation of data, analysis, or interpretation of results in this study; however, they were used as assistant tools under the supervision of a creative, humane mind. AI-assisted tools were employed for language editing and grammar improvement of the manuscript. All scientific content, conclusions, and interpretations were prepared and verified by the authors. The authors take full responsibility for the integrity and accuracy of the content presented in this paper.

Authors' Contributions
The study was designed by Amir Mohammad Hajati and Edris Mahdavi Fikjour. Amir Mohammad Hajati carried out the execution of the experiments. All authors contributed to the data analysis, as well as the writing and editing of the manuscript.

Availability of Data and Materials
Data will be made available upon request.

Conflict of Interest
The authors declare that they have no conflicts of interest related to this study.

Consent for Publication
Not applicable.

Ethical Considerations
This study was approved by the Ethics Committee of the International Association of Scientists (IAS) under the Code of Ethics IASECA.PEM.2506.2024.

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References

1. Asgarpanah J, Ramezanloo F. Chemistry, pharmacology and medicinal properties of Peganum harmala L. African Journal of pharmacy and pharmacology. 2012;6(22):1573-80. doi: 10.5897/AJPP11.876
2. Seidavi A, Tavakoli M, Slozhenkina M, Gorlov I, Hashem NM, Asroosh F, et al. The use of some plant-derived products as effective alternatives to antibiotic growth promoters in organic poultry production: a review. Environ Sci Pollut Res. 2021;28(35):47856-68. doi: 10.1007/s11356-021-15460-7

3. Shariatifar N, Mostaghim T, Afshar A, Mohammadpourfard I, Sayadi M, Rezaei M. Antibacterial Properties of Essential Oil of Heracleum persicum (Golpar) and Foodborne Pathogens. Int J Enteric Pathog. 2017;5(2):41-4. doi: 10.15171/ijep.2017.10
4. Rezayan A, Ehsani A. Evaluation of the Chemical Compounds and Antibacterial Properties of the Aerial Parts of Persian Heracleum Persicum Essence. Journal of Babol University of Medical Sciences. 2015;17(6):26-32.
5. Tong SYC, Davis JS, Eichenberger E, Holland TL, Fowler VG. Staphylococcus aureus Infections: Epidemiology, Pathophysiology, Clinical Manifestations, and Management. Clin Microbiol Rev. 2015;28(3):603-61. doi: 10.1128/CMR.00134-14
6. Otto M. Staphylococcus colonization of the skin and antimicrobial peptides. Expert Rev Dermatol. 2010;5(2):183-95. doi: 10.1586/edm.10.6
7. Alhadlaq MA, Aljurayyad OI, Almansour A, Al-Akeel SI, Alzahrani KO, Alsalman SA, et al. Overview of pathogenic Escherichia coli, with a focus on Shiga toxin-producing serotypes, global outbreaks (1982–2024) and food safety criteria. Gut Pathog. 2024;16(1):57. doi: 10.1186/s13099-024-00641-9
8. Han H, Li W, Liu J, Zhang X, Huo X, Sun Y, et al. Seven-year overview of antimicrobial resistance in diarrheagenic Escherichia coli from sporadic human diarrhea cases in 20 Chinese provinces. One Health Adv. 2024;2(1):29. doi: 10.1186/s44280-024-00064-w
9. Dini S, Singh S, Fatemi F. The Hepatoprotective Possession of Specific Iranian Medicinal Plants. Journal of Food Biochemistry. 2024;2024(1):8783113. doi: 10.1155/2024/8783113
10. Nawarathne MP, Dharmarathne C. Control of dengue larvae of Aedes aegypti and Aedes albopictus using the larvicidal bioactive compounds in different plant extracts and plant extract-mediated nanoparticles. Trop Med Health. 2024;52(1):95. doi: 10.1186/s41182-024-00654-9
11. Jubair N, Rajagopal M, Chinnappan S, Abdullah NB, Fatima A. Review on the Antibacterial Mechanism of Plant-Derived Compounds against Multidrug-Resistant Bacteria (MDR). Evid Based Complement Alternat Med. 2021;2021:1-30. doi: 10.1155/2021/3663315
12. Nazemi A, Hashemi M, Khataminejad MR, Pourshamsian K. Antimicrobial activity of aqueous and methanol extracts of Heracoleum Persicum. Medical Science Journal of Islamic Azad Univesity - Tehran Medical Branch. 2005;15(2):91-4.
13. Ehsani A, Rezaeiyan A, Hashemi M, Aminzare M, Jannat B, Afshari A. Antibacterial activity and sensory properties of Heracleum persicum essential oil, nisin, and Lactobacillus acidophilus against Listeria monocytogenes in cheese. Vet World. 2019;12(1):90-6. doi: 10.14202/vetworld.2019.90-96
14. Hazrati S, Mollaei S, Rabbi Angourani H, Hosseini SJ, Sedaghat M, Nicola S. How do essential oil composition and phenolic acid profile of Heracleum persicum fluctuate at different phenological stages? Food Sci Nutr. 2020;8(11):6192-206. doi: 10.1002/fsn3.1916
15. Javadian F, Saeidi S, Jahani S. Antimicrobial activity of Peganum harmala and Heracleum persicum against Acinetobacter baumannii. International Journal of Infection. 2016;3(1). doi: 10.17795/iji-33554
16. Miladinović DL, Ilić BS, Mihajilov-Krstev TM, Nikolić DM, Cvetković OG, Marković MS, et al. Antibacterial Activity of the Essential Oil of Heracleum Sibiricum. Natural Product Communications. 2013;8(9):1934578X1300800931. doi: 10.1177/1934578X1300800931
17. Fraternale D, Flamini G, Ricci D. Essential Oil Composition and Antimicrobial Activity of Angelica archangelica L. (Apiaceae) Roots. J Med Food. 2014;17(9):1043-7. doi: 10.1089/jmf.2013.0012
18. Sowndhararajan K, Deepa P, Kim M, Park SJ, Kim S. A Review of the Composition of the Essential Oils and Biological Activities of Angelica Species. Sci Pharm. 2017;85(3):33. doi: 10.3390/scipharm85030033
19. Alshibl HM, Al-Abdullah ES, Haiba ME, Alkahtani HM, Awad GEA, Mahmoud AH, et al. Synthesis and Evaluation of New Coumarin Derivatives as Antioxidant, Antimicrobial, and Anti-Inflammatory Agents. Molecules. 2020;25(14):3251. doi: 10.3390/molecules25143251
20. Shahrajabian MH, Sun W, Cheng Q. Chemical components and pharmacological benefits of Basil (Ocimum basilicum): a review. International Journal of Food Properties. 2020;23(1):1961-70. doi: 10.1080/10942912.2020.1828456
21. Radjabian T, Salimi A, Rahmani N, Shockravi A, Mozaffarian V. Essential Oil Composition of Some Wild Populations of Heracleum persicum Desf. Ex Fischer Growing in Iran. Journal of Essential Oil Bearing Plants. 2013;16(6):841-9. doi: 10.1080/0972060X.2013.862078
22. Betti N, Shia JS, Kadhum AAH, AlAmiery AA. Harnessing coumarin chemistry: Antibacterial antifungal and antioxidant profiling of novel coumarin derivatives. J Med Pharm Chem Res. 2024;6(10).
23. Grossman S, Fishwick CWG, McPhillie MJ. Developments in Non-Intercalating Bacterial Topoisomerase Inhibitors: Allosteric and ATPase Inhibitors of DNA Gyrase and Topoisomerase IV. Pharmaceuticals (Basel). 2023;16(2):261. doi: 10.3390/ph16020261
24. Douki T, Cadet J. Individual Determination of the Yield of the Main UV-Induced Dimeric Pyrimidine Photoproducts in DNA Suggests a High Mutagenicity of CC Photolesions. Biochemistry. 2001;40(8):2495-501. doi: 10.1021/bi0022543