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Phytochemistry and antimicrobial activity of Moroccan *Origanum compactum* and *Ruta montana* essential oils against nosocomial bacteria

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ABSTRACT

Introduction: Healthcare-associated infections are a global public health issue with far-reaching individual and economic repercussions. The microorganism's multi-resistance frequently increases the risk that can be lowered by using biomolecules of medicinal plant essential oils (EOs). This study investigated the phytochemical components and antimicrobial potential of the EOs of Moroccan *Origanum compactum* and *Ruta montana* gathered from Taza Region.

Methods: The EOs' chemical analysis was performed by GC/MS and their antimicrobial effects were assessed by the microplate dilution method against eight nosocomial resistant-bacterial strains.

Results: The main constituents of *O. compactum* EO were Thymol (29.56%), carvacrol (26.44%), γ-terpinene (18.86%) and *p*-cymene (12.01%), while those of *R. montana* EO were 2-undecanone (85.76%), 2-nonanone (3.95%), 2-decanone (3.67%) and 2-dodecanone (1.94%). The *O. compactum* EO had important antimicrobial effects on all bacteria experienced. The lower minimum inhibitory concentration (MIC) values were obtained for the tested *Staphylococcus* species (0.062%, 0.125% (v/v)) while the highest one (2% (v/v)) was obtained for *Klebsiella pneumonia* and *Pantoea* spp. The *R. montana* EO showed MIC values of 4% (v/v) for *Pantoea* spp. and 8% (v/v) for the other tested strains except *K. pneumonia* for which no effect was shown.

Conclusion: Therefore, these EOs, especially the *O. compactum* one, have an interesting antibacterial potential against nosocomial infections and might be used to develop new antimicrobial agents.

Implication for health policy/practice/research/medical education:
This study devoted on the phytochemistry and activity of *Ruta montana* and *Origanum compactum* essential oils. The results demonstrated that these essential oils, rich in active compounds, were powerful on nosocomial bacterial strains. So, they might be useful as natural disinfectants and antimicrobials in hospitals to minimize the risk of nosocomial infections, particularly those caused by multi-resistant bacteria.

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Introduction

Healthcare-associated infections are a serious public health problem worldwide and can prolong patients' hospitalization and significantly increase in healthcare costs (1). Bacteria are the most frequent cause of healthcare-associated infections (2), mainly through their antibiotic resistance inducing the development of some multi-drug resistant bacteria, which can limit the spectrum of efficient antimicrobials (3). According to O'Neill, infections due to antibiotic resistance will be the leading cause of death in the world by 2050 (4). In the United States, 99 000 people die each year from healthcare-associated infections due to bacteria that are resistant to antibiotics (5). The most worrisome bacterial strains that develop antimicrobial resistance include *Pseudomonas aeruginosa, Acinetobacter baumannii, Klebsiella pneumonia,* and *Staphylococcus aureus*, which are the most public reasons of hospital-acquired infections (2,6). Therefore, there is a great need to look for natural alternatives that have antibacterial effects, particularly against multi-resistant strains.

Currently, medicinal and aromatic plants are gaining much importance, because they can be used as drugs for the treatment of different health disorders. They represent a precious heritage for humanity (7). Morocco has a significant flora rich in endemic aromatic and medicinal plants, varying from one region to the next and constituting precious sources of essential oils (EOs), representing complex mixtures of natural molecules (8). EOs have been extensively used in aromatherapy, thanks to their significant health-promoting properties. Their primary functions are to reduce abiotic stress and aid in the defense mechanism against harmful microbes and herbivores (9,10). The EOs' active components own numerous beneficial effects such as antimicrobial, anti-inflammatory, antioxidant, and antitumor properties (11). Among the Moroccan medicinal and aromatic plants, *Origanum compactum* and *Ruta montana* play a significant role in the daily citizens' lives.

Indeed, *O. compactum* is widely used in traditional medicine as a remedy to treat diabetes, metabolic disorders, and digestive and respiratory diseases. It is also used and appreciated in many culinary preparations (11,12). *R. montana* has several therapeutic properties against infections and skin inflammations, neurological diseases, disorders of the vascular system, earache, and headache, as well as the treatment of psychic disorders (13,14).

Concerning *O. compactum*, of the Lamiaceae family, it is a perennial plant, 10–60 cm high, spreading thanks to its creeping rhizomes. It carries erect hairy stems that can be sterile (no flower) or fertile (which rise in flowering tops). The opposite hairy leaves are small (<2 cm long) with a pointed blade and a round base. The very small pink flowers, enveloped in purple bracts, are united at the top of stems in several dense and compact spikes, and bloom from May to September. The flowers are pollinated by insects and the seeds are blown off by the wind. The whole plant gives off an acrid and powerful aromatic fragrance due to its very fragrant EO. The distribution of this Mediterranean plant is limited to Northern Morocco and Southern Spain (12,15).

Ruta montana, of the family Rutaceae, is a 20-60 cm plant, glaucous, glabrous, glandular at the summit, has very beautiful evergreen foliage, bluish green, of oblong circumference, and finely cut into linear-obtuse segments, with a slightly wider terminal. The small yellow flowers, with delicately fringed petals, have awl-shaped, long-acuminate sepals. The fruiting cluster is dense, upright with pedicels shorter than the capsule, which is small, sub-globular, and depressed with four rounded lobes. Native to the Mediterranean rim, from Morocco to the Caucasus, *R. montana* possesses a potent fragrance appreciated by some people, fetid for others (16).

The current work intends to determine the chemical composition of Moroccan *O. compactum* and *R. montana* EOs and to evaluate their antimicrobial activities against microorganisms isolated from hospital surfaces, particularly those responsible for nosocomial infections.

Materials and Methods

Plant materials

Aerial parts of *O. compactum* and *R. montana* were collected in April and May 2022 respectively, in the region of Ait Sagherouchene, Taza (Morocco) (34°00′34″ N, 4°30′26″ W) and in the region of Bnilent, Taza (34°20′17″ N, 4°11′47″ W) (Morocco) and were shed-dried. Both plants were authenticated by Prof. A. Farah of the Medicinal and Aromatic Plant Group of the Laboratory. The vouchers of herbarium specimens (No BLMUP 351 and No BLMUP 352, respectively) were deposited at the laboratory herbarium of the Sciences and Technologies Faculty (Fez, Morocco).

Essential oil extraction

The newly harvested aerial parts of *O. compactum* and *R. montana* were hydro-distilled for 3 hours in a Clevenger-type apparatus containing 300 g of aerial plant parts with 2.5 L. The produced EOs were stored in the dark at 4 °C after being dried with anhydrous sodium sulphate to remove water traces.

Chemical analysis

The chemical compositions of the studied EOs were examined using a gas chromatograph (GC) (Hewlett-Packard 6890) coupled to a mass spectrometer (MS) (GC/MS) (Polaris Q ion trap) (17). The initial temperature was set for 5 minutes at 50 °C and then increased to 200 °C at 4 °C/min. The chromatography carrier gas was N_2 (1.8 mL/min). The mode used was Split (at a flow rate of 72.1 mL/min and a ratio of 1:50). The temperature was 250 °C

for both the injector and the detector and the dwell time was 48 min. An HP Chem Station computer system was employed to monitor the progression and management of these analyses. One microliter of diluted samples (1/20 in methanol) was injected manually. The EO's compounds were identified, thanks to their retention index (RI) and their MS, by comparison with the components reported in Wiley 09 and NIST 2002 databases.

Bacterial tested strains

Nosocomial pathogenic bacteria isolated from hospital surfaces in surgical wards, including *Staphylococcus aureus* and coagulase-negative *Staphylococcus* (gram-positive); and *Pseudomonas aeruginosa, Escherichia coli, Pantoea spp., Klebsiella pneumoniae, Escherichia hermannii, Stenotrophomonas maltophilia* (gram-negative bacteria) were tested in this study. These bacteria were resistant to broad-spectrum antibiotics frequently used in hospitals. Indeed, the antibiotics used belonged to different groups, including aminopenicillins (amoxicillin + clavulanic acid, amoxicillin), cephalosporin (ceftriaxone, cefoxitin), aminoside (tobramycin), and cyclins (tetracycline). Strains were revived through subculture in Luria-Bertani (LB) medium for 24 hours at 37 °C.

Antimicrobial activity

Minimum inhibitory concentration (MIC) values were determined by the microdilution test using a 96-well microplate according to the protocol previously described by Chraibi et al (18). The MIC is the lowest concentration of the EO producing an apparent full inhibition of the germ's growth.

The EOs tested were serially diluted in Mueller Hinton Broth supplemented with bacteriological agar (0.15% (w/v)) used as an emulsifier to reach concentrations of 8% to 0.003% (v / v). Then, 50 µL of the bacterial strain (10^6 CFU/mL) was added to each plate and incubated at 37 °C for 24 hours. Ten microliters of resazurin was then added to each well, as a bacterial growth indicator, to reveal microbial growth after an additional incubation during 2 hours by a coloration change from purple to pink. The MIC value was established as the highest concentration that prevented a color change of the resazurin.

The 12th well of the microplate was considered as the control for the growth of the bacterial strain. Each test was repeated three times in order to standardize the results.

Results

Chemical composition

The analysis of *O. compactum* EO (OCEO) by GC/MS (Figure 1) showed 24 components, representing 96.6% of the total EO. The main chemical compounds of this EO were thymol (29.56%), carvacrol (26.44%), β-terpinene (18.86%), *p*-cymene (12.01%) (Table 1). The *R. montana* EO (RMEO) analysis by GC/MS (Figure 2) showed ten components accounting for 100% of the total EO; the major components were 2-undecanone (85.76%), 2-decanone (3.67%), 2-nonanone (3.95%), and 2-dodecanone (1.94%) (Table 2).

Evaluation of the antimicrobial activity of essential oils

The antimicrobial activity assessment of *O. compactum* EO revealed remarkable and significant inhibitory activity against the eight bacteria tested, especially coagulase-negative *Staphylococcus*, *S. aureus,* and *S. maltophilia*, which showed high sensitivity to this EO and were reserved at very low concentrations of 0.062% (v/v), 0.125% (v/v), and 0.25%, respectively. In addition, the OCEO was more or less effective against *E. coli*, *P. aeruginosa*, and *Escherichia hermannii* with a MIC value of 0.5% (v/v). Whereas, *Pantoae* spp. and *K. pneumonia* were the least susceptible to *O. compactum* EO (MIC=2% (v/v)) (Table 3).

Furthermore, *R. montana* EO inhibited most of the

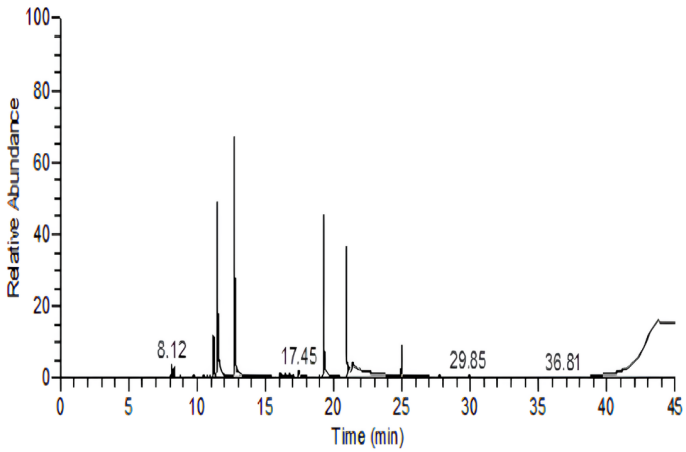

Figure 1. Chromatogram GC/MS of *Origanum compactum* essential oil with column temperature of 50 °C for 5 min, then a ramp with an increase of 4 °C/min up to 200°C. Each peak corresponds to a chemical compound detected by the mass spectrometer. The largest peaks correspond to: p-cymene (RT = 11.5 min), β-terpinene (RT = 12.98 min), thymol (RT = 19.42 min), and carvacrol (RT = 20.01 min), respectively.

Table 1. Chemical composition of the *Origanum compactum* essential oil

Compounds	RI	Concentration (%)	Chemical formula
α-Thujene	926	0.08	$C_{10}H_{16}$
α-Pinene	939	2.39	$C_{10}H_{16}$
Camphene	953	0.23	$C_{10}H_{16}$
1-Octene-3-ol	978	0.11	$C_8H_{16}O$
β-Pinene	980	0.23	$C_{10}H_{16}$
β-Myrcene	991	0.92	$C_{10}H_{16}$
α-Phellandrene	1005	0.16	$C_{10}H_{16}$
δ-3-Carene	1010	0.13	$C_{10}H_{16}$
α-Terpinene	1018	3.45	$C_{10}H_{16}$
p-Cymene	1026	12.01	$C_{10}H_{14}$
Limonene	1031	0.23	$C_{10}H_{16}$
1.8-Cineole	1033	0.05	$C_{10}H_{18}O$
γ-Terpinene	1062	18.86	$C_{10}H_{16}$
Terpinolene	1088	0.21	$C_{10}H_{16}$
Linalol	1098	0.26	$C_{10}H_{18}O$
Camphor	1136	0.17	$C_{10}H_{16}O$
Borneol	1165	0.40	$C_{10}H_{18}O$
Terpinen-4-ol	1177	0.30	$C_{10}H_{18}O$
α-Terpineol	1189	0.23	$C_{10}H_{18}O$
Thymol	1290	29.56	$C_{10}H_{14}O$
Carvacrol	1298	26.44	$C_{10}H_{14}O$
β-Caryophyllene	1418	1.95	$C_{15}H2_4$
γ-Cadinene	1513	0.12	$C_{15}H_{24}$
Caryophyllene oxide	1581	0.11	$C_{15}H_{24}O$
Total area percentage of IC		96.6 %	

RI, retention index.

bacterial strains tested with MIC values of 4% (v/v) for *Pantoea spp.* and 8% (v/v) for other bacterial strains, except

Table 2. Chemical composition of the *Ruta montana* essential oil

Compounds	RI	Concentration (%)	Chemical formula
Sabinene	897	0.53	$C_{10}H_{16}$
D-Limonene	1018	0.64	$C_{10}H_{16}$
2-Nonanone	1052	3.95	$C_9H_{18}O$
Eucalyptol	1059	0.36	$C_{10}H_{18}O$
2-Decanone	1151	3.67	$C_{10}H_{20}O$
2-Undecanone	1251	85.76	$C_{11}H_{22}O$
2-Undecanol	1277	1.70	$C_{11}H_{24}O$
2-Dodecanone	1350	1.94	$C_{12}H_{24}O$
2-Undecanol acetate	1417	0.80	$C_{13}H_{26}O_2$
2-Tridecanone	1449	0.64	$C_{13}H_{26}O$
Total area percentage of IC		100%	

RI, retention index.

Klebsiella pneumoniae for which no inhibitory activity was identified (Table 4).

Interestingly, concerning the antibiotic resistance profile, most bacteria isolated from hospital surfaces were resistant to several antibiotics. In this regard, these bacteria may present a high nosocomial risk for hospitalized patients. Fortunately, the comparison of the MIC values of *O. compactum* EO with the antibiotic resistance profile of these bacteria revealed a noteworthy effect against multi-resistant bacteria, especially against coagulase-negative *Staphylococcus* and *S. aureus* (Table 5).

Discussion

The results of the chemical composition analysis of the *O. compactum* EO showed a similarity with those of several studies, which found a dominance of carvacrol and thymol (19-21). These major components show a slight variation

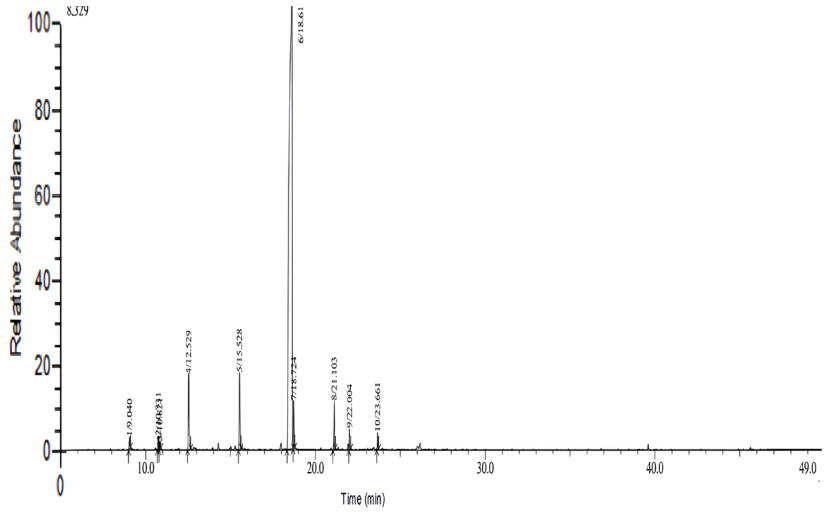

Figure 2. Chromatogram GC/MS of *Ruta montana* essential oil with column temperature of 50°C for 5 minutes, then a ramp with an increase of 4 °C/min up to 200 °C.

Table 3. Minimum inhibitory concentrations (MIC) of the *Origanum compactum* essential oil against the tested hospital bacterial strains

Bacterial strains	*Origanum compactum* MIC (% V/V)											
	8	4	2	1	0.5	0.25	0.125	0.062	0.031	0.015	0.007	0.003
Coagulase-negative *Staphylococcus*	-	-	-	-	-	-	-	-	+	+	+	+
Pseudomonas aeruginosa	-	-	-	-	-	+	+	+	+	+	+	+
Pantoea spp.	-	-	-	+	+	+	+	+	+	+	+	+
Klebsiella pneumoniae	-	-	-	+	+	+	+	+	+	+	+	+
Staphylococcus aureus	-	-	-	-	-	-	-	+	+	+	+	+
Escherichia hermannii	-	-	-	-	-	+	+	+	+	+	+	+
Escherichia coli	-	-	-	-	-	+	+	+	+	+	+	+
Stenotrophomonas maltophilia	-	-	-	-	-	-	+	+	+	+	+	+

Table 4. Minimum inhibitory concentrations (MIC) of the *Ruta montana* essential oil against the tested strains

Bacterial strains	*Ruta montana* MIC (% V/V)											
	8	4	2	1	0.5	0.25	0.125	0.062	0.031	0.015	0.007	0.003
Coagulase-negative *Staphylococcus*	-	+	+	+	+	+	+	+	+	+	+	+
Pseudomonas aeruginosa	-	+	+	+	+	+	+	+	+	+	+	+
Pantoea spp.	-	-	+	+	+	+	+	+	+	+	+	+
Klebsiella pneumoniae	+	+	+	+	+	+	+	+	+	+	+	+
Staphylococcus aureus	-	+	+	+	+	+	+	+	+	+	+	+
Escherichia hermannii	-	+	+	+	+	+	+	+	+	+	+	+
Escherichia coli	-	+	+	+	+	+	+	+	+	+	+	+
Stenotrophomonas maltophilia	-	+	+	+	+	+	+	+	+	+	+	+

in their quantity, mainly due to the variation of the plant's geographic origin, plant age, ripening season, and extraction procedure (19,22). Indeed, previous analyses of EOs of *O. compactum* from different geographical origins showed the presence of three essential components at variable rates: Thymol (0 to 43.4%), carvacrol (3.8% to 71%), and *p*-cymene (0 to 25.4%) (19).

Regarding the antibacterial activity of OCEO, our data are in line with those of prior work, which reported its antimicrobial effects. These effects could be mostly related to its chemical profile, which is very rich in thymol and carvacrol. Indeed, these compounds can impede the growth of both gram-positive and gram-negative bacteria (11,20-23). Furthermore, the major compounds present in the EO of *O. compactum* (thymol, carvacrol, and *p*-cymene) have synergistic effects with each other and additive effects with other minor compounds, which can reinforce the antibacterial actions (24).

In addition, other studies have shown that the antimicrobial activity of thymol and carvacrol is ascribed to the disruption of the lipid fraction of the bacterial membrane. Moreover, *p*-cymene can facilitate the intracellular penetration of carvacrol to increase its antibacterial potency. Therefore, the *p*-cymene potentiates the Carvacrol effect previously described (20). Furthermore, the *O. compactum* EO reacts in three phenological stages; first reducing the content of cellular DNA, then RNA and protein penetration, and finally disrupting the integrity of the cell membrane (25).

The analysis of the chemical composition of *R. montana* EO showed a predominance of 2-undecanone (85.76%), followed by 2-nonanone (3.95%) and 2-decanone (3.67%). These outcomes are comparable to those of other investigations informing that 2-undecanone is the main constituent of the *R. montana* EO. Indeed, several studies determined the presence of 2-undecanone at different percentages (63.97%, 60.19%, 67%) (14,26,27). Another study showed a variation in this percentage between 30.3% and 81.7% (28). Many factors can account for this variation in those compound rates, such as the environment, harvesting season, ecological parameters, as well as the extraction methods used, in addition to the test conditions (25).

The results of the antimicrobial activity of this EO are consistent with other studies that stated a moderate antimicrobial action on some microbial species, including *S. aureus, E. coli*, and *P. aeruginosa* (28,29). Moreover, another work reported that *R. montana* EO showed a great antibacterial effect on *E. coli, K. pneumoniae, P. aeruginosa,* and *S. aureus* (28). In addition, it has been

Table 5. Minimum inhibitory concentration (MIC) of the studied plants' essential oils and antibiotic resistance profile of multi-resistant bacteria isolated from hospital surfaces

	MIC% (v/v) RM	MIC% (v/v) OC	AMC	AX	CAZ	CFM	CN	CRO	CT	CTX	E	F	FOX	IPM	KF	L	NA	OX	PRL	RA	SXT	TE	TOB	TIC	TEC
Coagulase-negative *Staphylococcus*	8%	0.062%	R	R	R	R	R	S	R	R	R	S	R	S	R	S	R	R	R	S	S	S	S	R	R
Pseudomonas aeruginosa	8%	0.5%	R	R	R	R	S	R	S	R	R	R	R	S	R	S	S	R	R	R	S	S	R	R	R
Pantoea spp.	4%	2%	R	R	R	R	S	R	S	R	R	S	R	S	R	R	R	R	S	S	R	S	S	R	S
Klebsiella pneumonia	-	2%	R	R	R	R	S	R	S	R	R	R	R	S	R	R	S	R	R	S	S	S	R	R	R
Staphylococcus aureus	8%	0.125%	R	R	R	R	S	R	R	R	S	S	R	S	R	S	R	S	R	S	S	S	R	R	R
Escherichia hermannii	8%	0.5%	R	R	R	R	S	S	S	S	S	S	S	R	R	R	R	R	R	R	S	R	S	R	R
Escherichia coli	8%	0.5%	R	R	R	R	S	R	S	R	R	S	R	S	R	R	S	R	R	S	S	S	S	R	R
Stenotrophomonas maltophilia	8%	0.125%	R	R	R	R	S	R	S	R	R	R	R	R	R	R	S	R	R	S	S	S	S	R	R

Abbreviations: MIC, Minimum inhibitory concentration; AMC, Amoxicillin + clavulanic acid; AX, Amoxicillin; CAZ, Ceftazidime; CFM, Cefixime; CRO, Ceftraixone; CN, Cefalexine; CT, Cefotetan; CTX, Cefotaxime; E, Erythromycine; F, Acide fusidique; FOX, Cefoxitine; IPM, Imipeneme; KF, Cefalotine; L, Lincomycine; NA, nalidixic acid; OX, Oxacilline; PRL, Piperacilline; RA, Rifampicine; SXT, Trimethoprime-Sulfametoxazole; TE, Tetracycline); TIC, Ticarcilline; TOB, Tobramycine; TEC, Teicoplanine, R, Resistant; S, Sensible; *RM, Ruta montana; OC, Origanum compactum.*

reported that the antimicrobial activity of 2-Undecanone, the main compound of *R. montana* EO, is low against bacterial strains but high against yeasts (30,31).

Furthermore, our findings showed that the oregano EO had a more important effect on gram-positive bacteria (*Staphylococcus*) than on Gram-negative bacteria. This result is justified by the greater resistance of gram-negative bacteria, which can be assigned to their cell wall's structure and their outer membrane. Indeed, the outer membrane of Gram-negative bacteria is rich in lipopolysaccharide molecules, relatively impermeable to lipophilic compounds, thus presenting a barrier to the penetration of antimicrobial substances (20) making gram-negative bacteria more resistant than the gram-positive ones (19,24).

Concerning the comparison of *O. compactum* EO and antibiotic's MIC values, between the tested bacteria, significant antibacterial activity was revealed, with MIC values ranging from 0.062% to 0.125% (v/v) for gram-positive bacteria (*Staphylococcus*) and up to 2% (v/v) for Gram$^-$ bacteria (*Pantoae spp.* and *K. pneumoniae*) despite multi-drug resistance of all bacteria tested to antibiotics used (Table 3).

For *R. montana*, the MIC values varied from 4% (v/v) for Pantoea and to 8% (v/v) for other bacterial strains, except for *K. pneumoniae* for which no inhibition was detected. Mohammedi et al reported that *R. Montana* EO had a moderate antimicrobial effect against some bacterial strains, including *S. aureus, E. coli,* and *P. aeruginosa* (29). Furthermore, Benali et al cited that *R. montana* EO was more active against gram-positive bacteria thanks to the presence of 2-undecanone and 2-undecanol, known for their antimicrobial activities (14).

The comparison of the MIC values of *R. montana* EO and those of the antibiotics, revealed a more or less low antibacterial activity, with MIC values of 4% (v/v) for *Pantoea* spp. and 8% (v/v) for the remaining strains except *Klebsiella*.

Several studies have shown that the major components are most frequently responsible for the antibacterial effects (32,33). However, other studies have shown that in addition to the main compounds, the minor compounds play an imperative role in the antibacterial activity of the EO (34). Therefore, the major components may not usually determine the whole EOs' antibacterial activity, because the minor compounds and their combination may also have a part of responsibility in the complete activity. Moreover, the sensitivity of a bacterial to an EO depends on the characteristics of the microbial strains itself (32,35).

Finally, this study suggests that the *O. compactum* EO might be used in therapeutics as a natural alternative against the bacteria responsible for nosocomial infections. Indeed, it proved its potency against Gram-positive bacteria, especially those isolated from surgical departments in a hospital center, namely *S. aureus* previously recognized as the most common cause of surgical site infections (36). Therefore, we advise using this EO as a disinfectant of hospital surfaces in order to minimize the severity of infection related to hospital environments.

Conclusion

This work examined the chemical composition of Moroccan *O. compactum* and *R. montana* EOs, as well as their antibacterial powers against eight hospital-resistant bacterial strains leading to the cases of nosocomial infections in the surgical departments of a Moroccan hospital center. The GC-MS analysis revealed the presence of different bioactive compounds, mainly carvacrol, thymol, γ-terpinene, and *p*-cymene in *O. compactum* EO, and 2-undecanone as the major compound in *R. Montana* EO. Regarding the antibacterial activity, results showed that *R. montana* and *O. compactum* EOs were more potent on nosocomial bacterial strains, especially against *the* coagulase-negative *Staphylococcus* and *S. aureus*. Consequently, it is useful to use the studied EOs as natural disinfectants and antimicrobials in hospitals to minimize the risk of healthcare-associated infections, especially those due to multi-drug-resistant bacteria. However, more supplementary investigations are required to ensure the safety of the selected EOs.

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Authors' contributions

Conceptualization: Rachid Flouchi, Abdellah Farah, and Kawtar Fikri-Benbrahim
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Formal analysis: Rachid Flouchi, Marwa Chraibi, Abderrahim Elmniai, Ibrahim Touzani, and Kawtar Fikri-Benbrahim.
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Methodology: All authors.
Project administration: Kawtar Fikri-Benbrahim.
Resources: Kawtar Fikri-Benbrahim.
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Conflict of interests

The authors declare that there is no conflict of interest.

Ethical considerations

Ethical approval was obtained from the Faculty of Sciences and Technology Fes, Sidi Mohamed Ben Abdellah University

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The authors have paid close attention to ethical considerations concerning authorship, data collection, review, and analysis.

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References

1. Li Y, Gong Z, Lu Y, Hu G, Cai R, Chen Z. Impact of nosocomial infections surveillance on nosocomial infection rates: a systematic review. Int J Surg. 2017;42:164-9. doi: 10.1016/j.ijsu.2017.04.065.
2. Khan HA, Baig FK, Mehboob R. Nosocomial infections: epidemiology, prevention, control and surveillance. Asian Pac J Trop Biomed. 2017;7(5):478-82. doi: 10.1016/j.apjtb.2017.01.019.
3. Moreno PR, da Costa-Issa FI, Rajca-Ferreira AK, Pereira MA, Kaneko TM. Native Brazilian plants against nosocomial infections: a critical review on their potential and the antimicrobial methodology. Curr Top Med Chem. 2013;13(24):3040-78. doi: 10.2174/15680266113136660219.
4. O'Neill J. Antimicrobial Resistance: Tackling a Crisis for the Health and Wealth of Nations. Review on Antimicrobial Resistance; 2014.
5. Aslam B, Wang W, Arshad MI, Khurshid M, Muzammil S, Rasool MH, et al. Antibiotic resistance: a rundown of a global crisis. Infect Drug Resist. 2018;11:1645-58. doi: 10.2147/idr.s173867.
6. Kollef MH, Bassetti M, Francois B, Burnham J, Dimopoulos G, Garnacho-Montero J, et al. The intensive care medicine research agenda on multidrug-resistant bacteria, antibiotics, and stewardship. Intensive Care Med. 2017;43(9):1187-97. doi: 10.1007/s00134-017-4682-7.
7. Paw M, Begum T, Gogoi R, Pandey SK, Lal M. Chemical composition of *Citrus limon* L. Burmf peel essential oil from North East India. J Essent Oil Bear Plants. 2020;23(2):337-44. doi: 10.1080/0972060x.2020.1757514.
8. Bouyahya A, Bakri Y, Et-Touys A, Talbaoui A, Khouchlaa A, Charfi S, et al. [Resistance to antibiotics and mechanisms of action of essential oils against bacteria]. Phytothérapie. 2018;16(Suppl 1):S173-83. doi: 10.3166/phyto-2019-0147.
9. Lahlou M. The success of natural products in drug discovery. Pharmacol Pharm. 2013;4(3):17-31. doi: 10.4236/pp.2013.43A003.
10. Gogoi R, Sarma N, Begum T, Pandey SK, Lal M. North-East Indian *Chromolaena odorata (L.)* King and Robinson aerial part essential oil chemical composition, pharmacological activities - neurodegenerative inhibitory and toxicity study. J Essent Oil Bear Plants. 2020;23(6):1173-91. doi: 10.1080/0972060x.2020.1867009.
11. Bouyahya A, Abrini J, Dakka N, Bakri Y. Essential oils of *Origanum compactum* increase membrane permeability, disturb cell membrane integrity, and suppress quorum-sensing phenotype in bacteria. J Pharm Anal. 2019;9(5):301-11. doi: 10.1016/j.jpha.2019.03.001.
12. Bouyahya A, Jamal A, Edaoudi F, Et-Touys A, Bakri Y, Dakka N. *Origanum compactum* Benth: a review on phytochemistry and pharmacological properties. Med Aromat Plants. 2016;5(4):252. doi: 10.4172/2167-0412.1000252.
13. Barbouchi M, Benzidia B, Choukrad M. Chemical variability in essential oils isolated from roots, stems, leaves and flowers of three *Ruta* species growing in Morocco. J King Saud Univ Sci. 2021;33(8):101634. doi: 10.1016/j.jksus.2021.101634.
14. Benali T, Habbadi K, Khabbach A, Marmouzi I, Zengin G, Bouyahya A, et al. GC-MS analysis, antioxidant and antimicrobial activities of *Achillea odorata* subsp. *pectinata* and *Ruta montana* essential oils and their potential use as food preservatives. Foods. 2020;9(5):668. doi: 10.3390/foods9050668.
15. Bouyahya A, Zengin G, Belmehdi O, Bourais I, Chamkhi I, Taha D, et al. *Origanum compactum* Benth., from traditional use to biotechnological applications. J Food Biochem. 2020;44(8):e13251. doi: 10.1111/jfbc.13251.
16. Benkhaira N, Koraichi SI, Fikri-Benbrahim K. *Ruta montana* (L.) L.: an insight into its medicinal value, phytochemistry, biological properties, and toxicity. J Herbmed Pharmacol. 2022;11(3):305-19. doi: 10.34172/jhp.2022.36.
17. Chraibi M, Fikri-Benbrahim K, Ou-Yahyia D, Balouiri M, Farah A. Radical scavenging and disinfectant effect of essential oil from Moroccan *Mentha pulegium*. Int J Pharm Pharm Res. 2016;8(9):116-9. doi: 10.22159/ijpps.2016.v8i9.12434.
18. Chraibi M, Farah A, Lebrazi S, El Amine O, Iraqui Houssaini M, Fikri-Benbrahim K. Antimycobacterial natural products from Moroccan medicinal plants: chemical composition, bacteriostatic and bactericidal profile of *Thymus satureioides* and *Mentha pulegium* essential oils. Asian Pac J Trop. Biomed. 2016;6(10):836-40. doi: 10.1016/j.apjtb.2016.08.002.
19. Laghmouchi Y, Belmehdi O, Senhaji NS, Abrini J. Chemical composition and antibacterial activity of *Origanum compactum* Benth. essential oils from different areas at northern Morocco. S Afr J Bot. 2018;115:120-5. doi: 10.1016/j.sajb.2018.02.002.
20. Yousif L, Belmehdi O, Abdelhakim B, Skali Senhaji N, Abrini J. Does the domestication of *Origanum compactum* (Benth) affect its chemical composition and antibacterial activity? Flavour Fragr J. 2021;36(2):264-71. doi: 10.1002/ffj.3641.
21. Ouedrhiri W, Balouiri M, Bouhdid S, Moja S, Chahdi FO, Taleb M, et al. Mixture design of *Origanum compactum*, *Origanum majorana* and *Thymus serpyllum* essential oils: optimization of their antibacterial effect. Ind Crops Prod. 2016;89:1-9. doi: 10.1016/j.indcrop.2016.04.049.
22. Chahbi A, Nassik S, El Amri H, Douaik A, El Maadoudi EH, Boukharta M, et al. Chemical composition and antimicrobial activity of the essential oils of two aromatic plants cultivated in Morocco (*Cinnamomum cassia* and *Origanum compactum*). J Chem. 2020;2020:1628710. doi: 10.1155/2020/1628710.
23. Memar MY, Raei P, Alizadeh N, Aghdam MA, Kafil HS. Carvacrol and thymol: strong antimicrobial agents against resistant isolates. Rev Med Microbiol. 2017;28(2):63-8. doi: 10.1097/mrm.0000000000000100.
24. Bouhdid S, Skali SN, Idaomar M, Zhiri A, Baudoux D,

Amensour M, et al. Antibacterial and antioxidant activities of *Origanum compactum* essential oil. Afr J Biotechnol. 2008;7(10):1563-70.
25. Moussaoui F, Alaoui T. Evaluation of antibacterial activity and synergistic effect between antibiotic and the essential oils of some medicinal plants. Asian Pac J Trop. Biomed. 2016;6(1):32-7. doi: 10.1016/j.apjtb.2015.09.024.
26. Abdelwahab B, Amar Z, Noureddine G, Mesbah L, Salah R. Essential oil composition of Algerian *Ruta montana* (clus.) L. and its antibacterial effects on microorganisms responsible for respiratory infections. Adv Nat Appl Sci. 2011;5(3):264-9.
27. Boutoumi H, Moulay S, Khodja M. Essential oil from *Ruta montana* L. (Rutaceae) chemical composition, insecticidal and larvicidal activities. J Essent Oil Bear Plants. 2009;12(6):714-21. doi: 10.1080/0972060x.2009.10643780.
28. Djarri L, Ferhat M, Merabet G, Chelghoum A, Laggoune S, Semra Z, et al. Composition and antibacterial activity of the essential oil of *Ruta montana* from Constantine (Algeria). Der Pharm Lett. 2013;5(4):70-3.
29. Mohammedi H, Mecherara-Idjeri S, Hassani A. Variability in essential oil composition, antioxidant and antimicrobial activities of *Ruta montana* L. collected from different geographical regions in Algeria. J Essent Oil Res. 2020;32(1):88-101. doi: 10.1080/10412905.2019.1660238.
30. Gibka J, Kunicka-Styczyñska A, Gliñski M. Antimicrobial activity of undecan-2-one, undecan-2-ol and their derivatives. J Essent Oil Bear Plants. 2009;12(5):605-14. doi: 10.1080/0972060x.2009.10643763.
31. Kunicka-Styczyńska A, Gibka J. Antimicrobial activity of undecan-x-ones (x = 2-4). Pol J Microbiol. 2010;59(4):301-6.
32. Dorman HJ, Deans SG. Antimicrobial agents from plants: antibacterial activity of plant volatile oils. J Appl Microbiol. 2000;88(2):308-16. doi: 10.1046/j.1365-2672.2000.00969.x.
33. Kalemba D, Kunicka A. Antibacterial and antifungal properties of essential oils. Curr Med Chem. 2003;10(10):813-29. doi: 10.2174/0929867033457719.
34. Rota MC, Herrera A, Martínez RM, Sotomayor JA, Jordán MJ. Antimicrobial activity and chemical composition of *Thymus vulgaris*, *Thymus zygis* and *Thymus hyemalis* essential oils. Food Control. 2008;19(7):681-7. doi: 10.1016/j.foodcont.2007.07.007.
35. Nikaido H. Molecular basis of bacterial outer membrane permeability revisited. Microbiol Mol Biol Rev. 2003;67(4):593-656. doi: 10.1128/mmbr.67.4.593-656.2003.
36. Di Benedetto C, Bruno A, Bernasconi E. [Surgical site infection: risk factors, prevention, diagnosis and treatment]. Rev Med Suisse. 2013;9(401):1832-9. [French].