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Pharmacological activities and medicinal properties of endemic Moroccan medicinal plant *Origanum compactum* (Benth) and their main compounds

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ABSTRACT

Oregano [*Origanum compactum* Benth. (*O. compactum*), Lamiaceae] is an endemic Moroccan medicinal herb. It is used traditionally to fight against several disorders such as diarrhea, urolithiasis, hypertension, diabetes, and inflammation. A large number of components have been identified and isolated from the essential oil of this plant. Carvacrol, thymol, *p*-cymene and γ-Terpinene are among the more compounds presented in *O. compactum* essential oil and considered to be the main biologically active components. Numerous experimental studies showed that *O. compactum* organic extracts, essentials oil and its main compounds possess a broader spectrum of pharmacological and therapeutic activities such as antibacterial, antifungal, antioxidant, and anticancer activity. The present review attempts to give an overview of pharmacological studies of *O. compactum* and its major compounds.

1. Introduction

The man was always depending on the nature to live and survive. He had used products from different sources to fight against illnesses. Among these sources, we found aromatic and medicinal plants which have been used since ancient times for centuries as remedies for human diseases because of their vast biosynthetic capacity[1]. They are rich in a wide variety of secondary metabolites such as tannins, terpenoids, alkaloids and flavonoids with known therapeutic properties[2]. Actually, there are a growing number of studies for the biological effects of active compounds produced by medicinal plants during secondary metabolism.

The biosynthesis of secondary metabolites of medicinal plants is depending on geographical location, climate and environmental conditions in which a medicinal plant is growing[3,4]. The change of these parameters can totally induce gene expression and subsequently change metabolites compounds. Morocco, by its Mediterranean climate, is rich in vegetation including a spectrum of medicinal and aromatic plants.

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Among the most medicinal plant mostly found in Moroccan, we find oregano [*Origanum compactum* Benth. (*O. compactum*)]. Oregano is an endemic Moroccan medicinal plant which has widely been used by Moroccan population for its culinary and medicinal properties since antiquity[5,6]. Today, several studies have been conducted through Morocco areas for screening of pharmacological properties of *O. compactum* essential oils and extracts[7-12]. Therefore, this review presents an overview of the results found about phytochemical and pharmacological applications of *O. compactum* and its main compounds.

2. Overview on *O. compactum*

O. compactum (Figure 1) belongs to the family Lamiaceae and genus *Origanum* which is divided into 38 species, 6 subspecies and 18 hybrids that are mostly distributed in North Africa and Eurasia[13,14]. It is known in English as oregano and in Morocco it is known by its various vernaculars names such as "Zaatar" and "Sahtar" depending of areas. It is a perennial plant (chamaephyte) and has generally pubescent stems and covered with hairs. Oregano leaves are hairy especially in its lower faces and hair margins of long hairs. The inflorescences are dense spikes and short, very purple, large flowers opposite and the chalice is glabrous[15]. The floral bracts are lanceolate ovals ovoids-not membranous, stiff, leathery, sessile, truncate base, 6–8 mm long, glabrous on 2 sides, with inconspicuous glands, higher margin (top edge). The floral bracts overlap each other from the base

to the top of the ear and hide chalices[16]. The principal morphological characteristic of this species is the presence of secretary organ which synthesis and secretes essential oils.

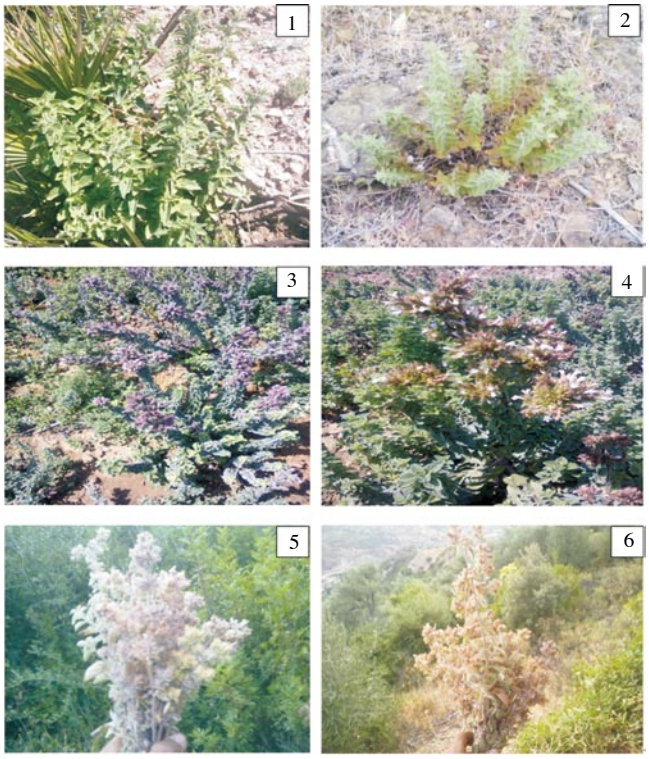

Figure 1. *O. compactum* collected from different geographical location at different phenological stages.
1 and 2: Vegetative stage; 3 and 4: Flowering stage; 5 and 6: Post-flowering stage.

Oregano with compact flowers is an endemic species from Morocco and Southern Spain (Southern Andalusia). In Morocco, *O. compactum* grows in the Rif, Tangerois, Central Northern Morocco, North-western Morocco, South-western Morocco, Haouz, the High Atlas and the south of the Iberian Peninsula (Spain)[3]. It grows naturally on dry rocky terrain (Figure 1), and sometimes grows between trees and shrubs and flowers from June to August. It is widespread in forests, plain and low mountains, rather limestone, on well-drained soil, up to 700 m above sea level. It is found in semi-arid and subhumid bioclimatic areas and with warm and fresh bioclimatic variants on floors of thermomediterranean and mesomediterranean vegetation[17].

3. Ethnomedical uses of *O. compactum*

Traditional herbal medicine is a discipline that studies the relationships that link humans to so-called medicinal plants. In the countries of the whole world and elsewhere in Morocco, this dictatorship has been widely applied since antiquity. Thanks to its rich Mediterranean climate, which offers an important plant biodiversity, Morocco has always used medicinal plants to treat certain pathologies. Indeed, several medicinal plants are constituted a therapeutic source for the Moroccan population. By the most widely used medicinal plants in Morocco, *O. compactum* is found at the most of these species. It is a plant considered a real drug in Morocco and it is applied against several pathologies with a spectrum of use which varies between the regions regarding to the pathologies, the parts used and the mode of preparation (Table 1). The aerial parts of this plant have been used for a long time against lung and gastrointestinal infections. The aerial part is used in Morocco in decoction or infusion as spasmolytic and sedative in the region of Ksar Kbir[28] and Zaër[26]. Leaves and stems are used in infusion and decoction against pathologies of the digestive system, cardiac diseases and sometimes against diabetes[20,21]. It is also used against constipation and bile acid pathologies as well as for increased appetite[24]. *O. compactum* leaves have been found various applications across Moroccan regions. They are prepared in decoction and/or infusion and administered orally against several pathologies such as diabetes[5,6,18], inflammation[19], hypertension[5,6], against pyelonephritis and cystitis[23], stomachic, febrifuge, against cooling and respiratory diseases[22].

4. Chemical compounds of *O. compactum*

4.1. Phenolic compounds

Polyphenolic compounds such as tannins, flavonoids, lignans and others phenylpropanoids derivates are biosynthesized from phenylalanine or tyrosine pathways by medicinal and aromatic plants[30,31]. Their phenol group gives them several biological properties such as antioxidant[32-35], anticancer[36], antimicrobial[37-

Table 1
Traditional use of *O. compactum*.

Region	Part used	Mode of preparation	Traditional use	References
South-east Morocco (Tafilalet)	Leaves	nd	Diabetes	[18]
Fez-Boulemane, Meknes-Tafilalet, Marrakech-Tensift-Al Haouz and Tanger-Tetouan region (Morocco)	Leaves	Infusion	Inflammation	[19]
Taounate province (Northern Morocco)	Leaves and stem	Infusion	Heart and intestinal pains	[20]
Oriental Morocco	Leaves and stem	Decoction, infusion and poudre	Pathologies of the digestive system, cold problems and diabetes	[21]
Oriental Morocco	Leaves	nd	Diabetes and hypertension	[5]
North centre region of Morocco (Fez–Boulemane)	Leaves	nd	Diabetes and hypertension	[6]
Haut Atlas oriental (Haute Moulouya) (Morocco)	Leaves	Decoction	Stomachic, febrifuge, against cooling and respiratory diseases	[22]
City of Tan-Tan (Sahara Moroccan)	Leaves	Infusion	Urolithiasis	[23]
Province of Settat (Morocco)	Leaves and stem	Infusion	Aerophagia, colitis, cellulites, constipation, painful periods and to increase appetite	[24]
		Decoction	Bronchopulmonary, mouth, gastrointestinal and biliary disorders	[24]
City of Khenifra (Morocco)	Leaves and stem	Decoction	Against cooling and diarrhea disorders	[25]
Region of Zaër (Morocco)	Aerial part	Infusion or decoction	Digestive and bronchial disorders	[26]
North west of Morocco	Leaves and inflorescence	Infusion or decoction	Hypertension and diarrhea	[27]
Ksar Lakbir district (North west of Morocco)	Aerial part	Infusion	Spasmolytic and sedative	[28]
Ouezzane (North west of Morocco)	Flowering top	Decoction	Against stomach disorders and febrifuge	[29]

nd: Not determined.

41] and litholytic activity[42,43]. A few studies have been investigated the chemical composition of *O. compactum* essential oils. Then, phenolic compounds have not yet been determined exactly. El Babili *et al*. have determined the total phenols, flavonoids, tannins and anthocyanins of *O. compactum* ethyl acetate, petroleum ether, ethanol and decoction extracts[44]. The petroleum ether extract possesses the highest level of polyphenols (707.8 ± 13.4 mg equivalent gallic acid), tannins (510.3 ± 13.7 mg equivalents catechin), and anthocyanins (5.63 ± 0.19 mg equivalent cyanindin) than others extracts. While, ethyl acetate and decoction extracts have possessed the most flavonoids content at (54.7 ± 1.8) and (52.9 ± 1.6) mg equivalent quercetin, respectively. In other early study, researchers have found the present of the phenols, flavans, flavonoids, leucoanthocyanins, saponins sterols and terpenoids[45]. Some chemical molecules have been identified from *O. compactum* extracts, including thymohydroquinone, betulinic acid, β-amyrin, betulin, oleanolic acid, ursolic acid, aromadendrin, 21 α-hydroxyuleanolic acid and 21 α-hydroxyursolic acid[46].

4.2. Essential oils

From a biological point of view, essential oils are substances obtained from a plant material by extraction procedures such as steam distillation, hydro-distillation, dry distillation and mechanical extraction from the epicarp of certain plants such as citrus. From the biochemical point of view, essential oils are complex mixtures of natural compounds with various organic structures (except the fatty substances contained in vegetable oils)[47]. The word oil is attributed to its hydrophobic character and to its solubilizing properties in fats, whereas the essential word reflects the distinctive odor emitted by the producing plant.

Essential oils are biometabolized by so-called aromatic plants as secondary metabolites and usually have the characteristic odor of the producing plant. The chemical composition of an essential oil is formed essentially of terpenic compounds and their oxygenated derivatives[38]. Essential oils posses numerous pharmacological properties such as antibacterial, antitumor, antioxidant, antifungal and anti-inflammatory[47-49].

O. compactum has a special structure which synthesizes and secretes essential oils. The yield of this oil is depending on part of plant used, the area of collection and method of extraction used. Several studies have been focused on the chemical composition of *O. compactum* essential[3,4,50]. This oil is rich in terpenic and phenolic compounds such as α-thujene, myrcene, α-terpinene, *p*-cymene, γ-terpinene, cis-sabinene hydrate, linalool, α-terpineol, carvacryl methyl oxide, thymol, carvacrol, and (*E*)-β-caryophyllene[4,44].

There are four main compounds presents in *O. compactum* essential oils, *viz*. carvacrol, thymol, *p*-cymene and γ-terpinene. The content of these molecules in oregano oil is varied depending on the area of collection, phonological stage of plant and storage condition of oils. Table 2 summarizes fluctuations of percentage content of each of these molecules in oregano oil through Morocco regions[3,4]. It is seen clearly that carvacrol and thymol always present with high proportion, while γ-terpinene and *p*-cymene present with low proportion.

5. Pharmacological properties

In vitro studies on revealed that the extracts, essential oils and their derivates extracted from *O. compactum* showed several biological activities such as antibacterial, antioxidant, antitumor and antifungal. These activities are due the presence of bioactive components such as phenolic and terpenic group.

5.1. Antibacterial properties

Antibiotics have been a revolution in medicine since their first appeared. However, the co-evolution of the microorganisms on the one hand and the misuse of these antibiotics on the other hand were led to the appearance of resistant or even multiresistant forms against these antibiotics[38]. Natural products from medicinal plants have been able to overcome the challenge of antibiotics[32,36,40,41]. *O. compactum* has proved its candidacy in the inhibition of bacteria pathogenic strains including those which resist to antibiotics[50]. Several accumulative studies (Table 3) have revealed the antibacterial activity of *O. compactum* extracts and essential oils[8,10,50,56,61,62]. Indeed, essential oils inhibited the growth of Gram-negative bacteria

Table 2
Main chemical compounds of *O. compactum* essential oils.

Sample	Constituent (%)				References
	Carvacrol	Thymol	*p*-cymene	γ-terpinene	
Morocco	3.8.00–71.00	0.00–43.40	10.70–25.40	–	[51]
Rabat Morocco	58.10	9.00	11.40	7.10	[52]
Morocco	22.00	19.00	–	23.00	[53]
Tetouan Morocco	30.53	27.50	7.89	18.20	[50]
Morocco	36.46	29.74	24.31	1.10	[44]
Taounat Morocco	43.97	11.56	17.87	8.43	[8]
Taounate region (Morocco)	47.85	15.75	8.44	17.25	[10]
Larache	42.90	4.80	14.80	22.60	[54]
Tetouan Morocco	29.70	2.20	11.50	30.10	
Tetouan Morocco	6.70	28.30	11.60	26.70	
Morocco	31.22	22.67	12.99	18.60	[3]
Tetouan Morocco	68.992	18.671	2.531	3.979	[9]
nd	41.80	16.20	11.40	16.60	[55]
Pronarôm International (Ghislenghien, Belgium)	22.00	19.36	13.26	22.90	[52]
Pronarôm International (Ghislenghien, Belgium)	46.88	15.26	13.10	11.61	[7]
Pranarôm International (Ghislenghien, Belgium)	46.37	13.70	13.33	-	[56]
Ouazzane (North-West Morocco)	37.70	17.70	12.10	-	[57]
Morocco	49.52	1.57	21.22	14.21	[58]
Morocco	55.90	0.20	8.60	15.10	[59]
Al Hoceima (Northern Morocco)	59.10	9.10	11.70	1.10	[45]
nd	20⩾ % ⩽ 40	15 ⩾ % ⩽ 30	10 ⩾ % ⩽ 25	4 ⩾ % ⩽ 25.5	[60]

nd: Not determined.

Table 3
Pharmacological properties of *O. compactum.*

Biological Activity	Part used	Type of extract	Main compound	Used method	Tested organism	Effects	References
Antibacterial	Aerial part	EO	nd	Inhibition of bacteria strains in Baby-leaf salad	*E. coli* O157:H7	0.5 log reductions after 5 days of storage of baby-leaf salads treated with 10% EO	[7]
	Flowering tops	EO	Carvacrol Thymol γ-Terpinene *p*-Cymene	Broth dilution method	*P. aeruginosa* ATCC 27853	MIC = 1% (v/v)	[61]
					S. aureus ATCC 29213	MIC = 0.031% (v/v)	
	Flowering tops	EO	Carvacrol Thymol γ-Terpinene *p*-Cymene	Well diffusion and broth dilution methods	*S. aureus* MBLA	Ø = 27 mm MIC = 0.007 8% (v/v) MBC = 0.007 8% (v/v)	[50]
					S. aureus CECT 976	Ø = 12 mm MIC = 0.031 2% (v/v) MBC = 0.125 0% (v/v)	
					S. aureus CECT 794	Ø = 10 mm MIC = 0.031 2% (v/v) MBC = 0.062 5% (v/v)	
					B. subtilis DCM 6633	Ø = 25 mm MIC = 0.031 2% (v/v) MBC = 0.031 2% (v/v)	
					Enterococcus faecium CECT 410	Ø = 25 mm MIC = 0.031 2% (v/v) MBC = 0.031 2% (v/v)	
					E. coli K12 MBLA	Ø = 20 mm MIC = 0.062 5% (v/v) MBC = 0.062 5 % (v/v)	
					E. coli serovar O157:H7 CECT 4076	Ø = 20 mm MIC = 0.125% (v/v) MBC = 0.25% (v/v)	
					Proteus mirabilis IH	Ø =32 mm MIC = 0.062 5% (v/v) MBC = 0.062 5% (v/v)	
					Listeria innocua CECT 4030	Ø = 32 mm MIC = 0.031 2% (v/v) MBC = 0.031 2% (v/v)	
					L. monocytogenes serovar 4b CECT 4032	Ø =15.5 mm MIC = 0.062 5% (v/v) MBC = 0.125% (v/v)	
					Pseudomonas fluorescens CECT 378	Ø = 5 mm MIC = 0.250 0% (v/v)	
					P. aeruginosa IH	MIC > 1% (v/v) MBC > 1% (v/v)	
					P. aeruginosa CECT 110T	Ø = 2 mm MIC > 1% (v/v) MBC > 1% (v/v)	
					P. aeruginosa CECT 118	Ø = 1 mm MIC = 1% (v/v) MBC > 1% (v/v)	
	Leaves and stems	EO	Carvacrol Thymol γ-terpinene p-cymene	Agar disc diffusion andmicrodilution method	*S. aureus*	Ø = 46.66 mm MIC = 0.125% (v/v) MBC = 0.125% (v/v)	
					B. subtilis	Ø = 41.66 mm MIC = 0.031% (v/v) MBC = 0.062% (v/v)	
					E. coli	Ø = 34.33 mm MIC = 0.062% (v/v) MBC = 0.125% (v/v)	
					P. aeruginosa	Ø = 9mm MIC > 4% (v/v) MBC > 4% (v/v)	
	Flowering plant	EO	Carvacrol Thymol γ-terpinene	Agar-disc diffusion and microdilution method	*L. monocytogenes* NCTC 11994	Ø = 26.8 ± 0.6 mm	[56]
					L. monocytogenes S0580	Ø = 26.8 ± 0.5 mm	
					Salmonella typhimurium ATCC 14028	Ø = 16.6 ± 0.3 mm	
					Salmonella typhimurium S0584	Ø = 23.7 ± 0.5 mm	
					E. coli O157:H7 ATCC 35150	Ø = 15.4 ± 0.2 mm	
					E. coli O157:H7 S0575	Ø = 17.5 ± 0.3 mm	

(*continued on next page*)

Table 3 (*continued*)

Biological Activity	Part used	Type of extract	Main compound	Used method	Tested organism	Effects	References
	Aerial part	EO	Carvacrol Thymol γ-Terpinene *p*-Cymene	Disk diffusion and broth dilution methods	*Staphylococcus pyogenes*	Ø = 12 mm MIC = 0.75% (v/v)	[55]
	Leaves	EO	Carvacrol Thymol γ-Terpinene *p*-Cymene		*E. coli*	EO at 0.03% or 0.06% showed an inhibitory activity against *E. coli* O157:H7, *E. coli* ATCC 25922 and *E. coli* cocktail during storage at 25 °C and at 7 °C in casings	[62]
	Flowers, leaves and stems	EO	Carvacrol Thymol *p*-Cymene	Disc diffusion method Micro broth dilution method	*Salmonella* spp. 1	Ø = 30 mm MIC = 0.3125% (v/v) MBC = 0.3125% (v/v)	[8]
					Salmonella spp. 2	Ø = 30 mm MIC = 0.3125% (v/v) MBC = 0.625% (v/v)	
					Salmonella spp. 3	Ø = 30 mm MIC = 0.625% (v/v) MBC = 0.625% (v/v))	
					Salmonella spp. 4	Ø = 32.5 ± 2.12 mm MIC = 0.3125% (v/v) MBC = 0.3125 % (v/v)	
					Salmonella spp. 5	Ø = 34.5 ± 2.12 mm MIC = 0.3125% (v/v) MBC = 0.3125% (v/v)	
	Aerial parts	EO	Carvacrol Thymol γ-Terpinene *p*-Cymene	Agar disc diffusion method Microdilution method	*S. aureus*	Ø = 46.66 ± 2.88 mm MIC = 0.125% (v/v) MBC = 0.125% (v/v)	[10]
					B. subtilis	Ø = 41.66 ± 2.88 mm MIC = 0.031% (v/v) MBC = 0.062% (v/v)	
					E. coli	Ø = 34.33 ± 8.32 mm MIC = 0.062% (v/v) MBC = 0.125% (v/v)	
					P. aeruginosa	Ø = 9.00 ± 1.00 mm MIC > 4% (v/v) MBC > 4% (v/v)	
		Methanol extract	nd	Agar well diffusion assay	*E. coli* K12	Ø = 8.00 ± 2.4 mm	[33]
					S. aureus	Ø = 14.00 ± 0.75 mm	
					L. monocytogenes	Ø = 26.00 ± 2.00 mm	
					P. aeruginosa	na	
		Ethanol extract	nd	Agar well diffusion assay	*E. coli* K12	Ø = 8.00 ± 2.40 mm	
					S. aureus	Ø = 14.00 ± 0.75 mm	
					L. monocytogenes	Ø = 26.00 ± 2.00 mm	
					P. aeruginosa	na	
		n-Hexane extract	nd	Agar well diffusion assay	*E. coli* K12	Ø = 8.00 ± 2.40 mm	
					S. aureus	Ø = 14.00 ± 0.75 mm	
					L. monocytogenes	Ø = 26.00 ± 2.00 mm	
					P. aeruginosa	na	
		Ethyl acetate	nd	Agar well diffusion assay	*E. coli* K12	Ø = 8.00 ± 2.40 mm	
					S. aureus	Ø = 14.00 ± 0.75 mm	
					L. monocytogenes	Ø = 26.00 ± 2.00 mm	
					P. aeruginosa	NA	
Antioxidant	Leaves	EO	nd	ABTS assay	nd	IC_{50} = 2.0 ± 0.1 µg/mL	[44]
				DPPH assay		IC_{50} = 60.1 ± 3.3 µg/mL	
		Ethyl acetate extract		ABTS assay		IC_{50} = 7.2 ± 0.3 µg/mL	
				DPPH assay		IC_{50} = 33.9 ± 0.8 µg/mL	
		Petroleum ether extract		ABTS assay		IC_{50} = 17.4 ± 0.8 µg/mL	
				DPPH assay		IC_{50} = 99.5 ± 2.5 µg/mL	
		Ethanol extract		ABTS assay		IC_{50} = 9.6 ± 0.3 µg/mL	
				DPPH assay		IC_{50} = 9.9 ± 0.3 µg/mL	
		Decoction		ABTS assay		IC_{50} = 7.9 ± 0.3 µg/mL	
				DPPH assay		IC_{50} = 4.8 ± 0.2 µg/mL	
	Aerial part	EO	Carvacrol Thymol	DPPH assay		IC_{50} = 137.60 ± 14.26 µg/mL	[9]

Table 3 (*continued*)

Biological Activity	Part used	Type of extract	Main compound	Used method	Tested organism	Effects	References
	Flowers, leaves and stems	EO	Carvacrol Thymol *p*-Cymene	β-Carotene linoleic acid assay		I% = 84.55 ± 1.02 μg/mL	[11]
				DPPH assay		IC_{50} = 0.021 ± 0.004 mg/mL	
				TBARS assay		IC_{50} = 305.32 ± 3.21 mg/mL	
		Methanol extract	nd	DPPH assay		IC_{50} = 48.34 μg/mL	[34]
		Ethanol extract		DPPH assay		IC_{50} = 74.25 μg/mL	
		n-Hexane extract		DPPH assay		IC_{50} = 39.83 μg/mL	
		Ethyl acetate extract		DPPH assay		IC_{50} = 137.35 μg/mL	
Antitumor		EO	nd	(3H)-hypoxanthine incorporation assay	Human breast cancer cells MCF7	IC_{50} > 100 μg/mL	[44]
		Ethyl acetate extract	nd	3H)-hypoxanthine incorporation assay	Human breast cancer cells MCF7	IC_{50} = 30 μg/mL	
		Petroleum ether extract	nd	3H)-hypoxanthine incorporation assay	Human breast cancer cells MCF7	IC_{50} = 70 μg/mL	
		Ethanol extract	nd	3H)-hypoxanthine incorporation assay	Human breast cancer cells MCF7	IC_{50} = 56 μg/mL	
		Decoction	nd	3H)-hypoxanthine incorporation assay	Human breast cancer cells MCF7	IC_{50} > 100 μg/mL	
	Aerial part	Ethyl acetate extracts	nd	MTT assay	A549 lung cancer	IC_{50} =198 ± 12 μg/mL	[63]
				MTT assay	SMMC-7721 hepatoma cells	IC_{50} = 266 ± 14 μg/mL	
	Aerial part	Ethyl acetate	nd	MTT assay	Human breast cancer cell line MCF-7	IC_{50} = 275.05 ± 14.00 μg/mL	[64]
		Methanol	nd	MTT assay		IC_{50} = 374.01 ± 16.00 μg/mL	
Antifungal	Aerial aprt	EO	*p*-Cymene γ-Terpinene Carvacrol Thymol	Incorporation in a solid medium assay	*Botrytis cinerea*	IC_{50} = 35.1 ppm	[52]
	Aerial part	Petroleum ether	nd	Incorporation in a solid medium assay	*Penicillium digitatum*	At 2 000 ppm, inhibition = 83%	[65]
		Hexane	nd			At 2 000 ppm, inhibition = 35.3%	
		Chloroform	nd			At 2 000 ppm, inhibition = 29.4%	
		Methanol	nd			At 2 000 ppm, inhibition = 45.9%	
Antimalaria	Leaves	EO	nd	(3H)-hypoxanthine incorporation	*P. falciparum*	IC_{50} = 34 μg/mL	[44]
		Ethyl acetate extract	nd	(3H)-hypoxanthine incorporation	*P. falciparum*	IC_{50} = 33 μg/mL	
		Petroleum ether extract	nd	(3H)-hypoxanthine incorporation	*P. falciparum*	IC_{50} > 100 μg/mL	
		Ethanol extract	nd	(3H)-hypoxanthine incorporation	*P. falciparum*	IC_{50} > 100 μg/mL	
		Decoction	nd	(3H)-hypoxanthine incorporation	*P. falciparum*	IC_{50} = 90 μg/mL	
Mutagenic	Flowering tops	EO	Carvacrol Thymol γ-Terpinene *p*-Cymene	Somatic mutation and recombination test (SMART)	*Drosophila melanogaster*	na	[65]
Antimutagenic	Flowering tops	EO	Carvacrol Thymol γ-Terpinene *p*-Cymene	Somatic mutation and recombination test (SMART) by indirect-acting mutagen urethane (URE) and direct-acting mutagen methyl methanesulfonate (MMS)	*Drosophila melanogaster*	Strong inhibitory effect against URE-induced mutagenicity Weak inhibitory effect on the mutagenicity induced by MMS was observed	[65]
Anticorrosion activity	Aerial part	EO	Petroleum Ether Hexane Chloroform Methanol	Potentiodynamic polarization and electrochemical impedance spectroscopy assay	nd	A promising inhibitory corrosion	[52]

Table 3 (*continued*)

Biological Activity	Part used	Type of extract	Main compound	Used method	Tested organism	Effects	References
Anti-glycan activity	Aerial part	EO	Carvacrol Thymol	Polyacrylamide gel electrophoresis	nd	na	[9]
Genotoxicity	Flowers, leaves and stems	EO	Carvacrol Thymol *p*-Cymene	Micronucleus assay and proliferation index	Human lymphocytes	Is not genotoxic at low concentration	[12]
Insecticidal activity	-	EO	nd	Fumigation or topical application	*Spodoptera littoralis*	LD_{50} = 0.041 mL/larva	[66]
Molluscicidal activity	Aerial part	Petroleum ether	nd	nd	*Bulinus truncatus*	LC_{50} = 85.17 ppm	[67]
		Hexane				LC_{50} = 17.77 ppm	
		Dichloromethane				LC_{50} = 8.22 ppm	
		Ethyl acetate				LC_{50} < 1 ppm	
		Methanol				LC_{50} = 33.49 ppm	
Antileishmanial activity	Flowering tops	Methanol	Polyphenols and flavonoids	MTT assay	*L. major*	> 500	[68]
					L. tropica	> 500	
					L. infantum	> 500	
		Ethanol	Polyphenols and flavonoids	MTT assay	*L. major*	> 500	
					L. tropica	> 500	
					L. infantum	474.67 ± 4.77	
		n-Hexane	Polyphenols and flavonoids	MTT assay	*L. major*	482.16 ± 1.55	
					L. tropica	275.94 ± 5.76	
					L. infantum		

MIC: Minimum inhiitory concentraion; MBC: Minimum bactericidal concentration; nd: Not determined; na: Not active; *E. coli*: *Escherichia coli*; *P. aeruginosa*: *Pseudomonas aeruginosa*; *S. aureus*: *Staphylococcus aureus*; *B. subtilis*: *Bacillus subtilis*; *L. monocytogenes*: *Listeria monocytogenes*; *B. cinerea*: *Botrytis cinerea*; *P. falciparum*: *Plasmodium falciparum*; *L. major*: *Leishmania major*; *L. tropica*: *Leishmania tropica*; *L. infantum*: *Leishmania infantum.*

and Gram-positive bacteria at low concentrations with a MIC of 0.007 8% (v/v) against *S. aureus*[50]. Mechanisms of action of this oil were investigated against *S. aureus* and *P. aeruginosa* using flow cytometry and scanning electron microscopy[61]. In addition to leakage in ions transport, the oil has induced morphological and structural deformations leading to cell death[61]. In another study, the *O. compactum* essential oil extracted from the aerial part is shown efficacy in the inhibition of *Staphylococcus pyogenes* at a concentration of MIC = 0.75% (v/v)[56]. *Salmonella* species was also inhibited by *O. compactum* essential oil extracted from aerial part[8]. In addition to this bacteriostatic action, this oil has a bactericidal action against *Salmonella* at low concentration which suggests this application against diseases and food deterioration caused by *Salmonella* species.

Organic extracts from *O. compactum* have also showed significant antibacterial effect. Indeed, Bouyahya *et al.*[34] have tested the antibacterial activity of the methanol, ethanol, ethyl acetate and *n*-hexane extracts of flowering tops against for pathogenic strains (*E. coli*, *S. aureus*, *L. monocytogenes* and *P. aeruginosa*). All extracts showed important bacterial tested with some variability, and these results are not correlated with the amount of phenolic and flavonoid contents of extracts which indicate the presence of specific bioactive molecules that inhibit bacterial growth. Interesting in this results, *n*-hexane extract showed significant zone diameter especially against *P. aeruginosa* (Ø = 9.0 ± 1.5 mm); species revealed multi-resistance against antibiotics[34].

5.2. Antioxidant properties

Oxidative stress is defined as disequilibrium in the transfer of electrons in living systems. This stress is mainly due to the free radicals resulting from incomplete oxidation reactions of oxygen (reactive oxygen species) or of nitrogen (reactive nitrogen species) [69]. In homeostasis situation, oxygen reactive intermediates are eliminated by enzymatic catalytic (glutathione peroxidase, superoxide dismutase and catalase) and non-enzymatic systems (vitamins, carotenoids, polyphenols and flavonoids)[70].

Oxidative stress is now considered a major challenge, and its elimination takes an importance for human health. It has become an etiological factor for much serious pathology such as cancer, cardiovascular diseases and neurodegenerative pathologies[71,72]. Synthetic antioxidants have revealed side effects that exceed their actual pharmacological effects, hence natural products are considered as important antioxidants. In this way, medicinal plants are promising sources[48,73]. Essential oils and extracts of *O. compactum* have shown their ability in reducing free radicals[9,44,50,74] (Table 3). *O. compactum* essential oil was tested by Bouhdid *et al.* and showed its ability to reduce the DPPH radical, iron and β-carotene in a dose-dependent manner and significantly with standard antioxidants[50]. This oil was also tested for its antioxidant effects using DPPH and ABTS methods and showed the IC_{50} values respectively at IC_{50} = 2.0 ± 0.1 μg/mL and IC_{50} = 60.1 ± 3.3 μg/mL[44]. Whereas Amakran *et al.*[9] found an IC_{50} = 137.60 ± 14.26 μg/mL. The difference between the results obtained is due to the difference in the chemical composition[9]. Petroleum ether, ethanol and ethyl acetate extracts of *O. compactum* are also shown to be antioxidants at significant concentrations compared to standard antioxidants[44].

5.3. Anticancer properties

Cancer is a complex disease of various etiologic and multiple risk factors. It can be generated by genetic, epigenetic, nutritional,

environmental and physiological perturbations[75-77]. Cancer presents several pathologies that are distinguished from one to another according to the cellular tropism. The fight against this disease is controversial by the development of the resistance of the tumor cells against the chemotherapy (multi-drug resistance) and by the difficulty related to the application of other treatments. Medicinal plants have found their contributions in the development of anticancer drugs[16,34,49]. *O. compactum* has been tested by some studies and showed cytotoxic effects against some tumor cell lines[44,63,64] (Table 3). The essential oil, decoction, ethanol, ethyl acetate and petroleum ether extracts of *O. compactum* were all able to inhibit the breast cancer line MCF7[44]. Using the (3H)-hypoxanthin incorporation assay, authors proved the cytotoxicity of *O. compactum* decoction extract and essential oil against MCF-7 cell line at an IC_{50} > 100 μg/mL. While, the IC_{50} of petroleum ether, ethanol and ethyl acetate were respectively IC_{50} = 70, IC_{50} = 56, IC_{50} = 30 μg/mL. On the other hand, the ethyl acetate extract of the aerial part tested against the same tumor line (MCF7) using the MTT assay showed an IC_{50} = 275.05 ± 14.00 μg/mL[64]. The antitumor activity *in vitro* of plants extracts is depending in fact on several parameters such as the part of the plant used and the method used. The ethyl acetate extract of the aerial part from *O. compactum* is tested by Chaouki *et al.*[63] against two human tumor lines (A549 lung cancer tumor line and a SMMC-7721 hepatic tumor cell line). The cytotoxicity obtained for the two lines A549 and SMMC-7721 is respectively IC_{50} = 198 ± 12 and IC_{50} = 266 ± 14 μg/mL[63]. Cytotoxic effect of ethyl acetate extract is mainly dedicated to apoptosis which has been shown by fragmentation of genomic DNA in two tested cell lines. The induction of apoptosis pathway is related to the modulation of some Bcl-2 family genes[63].

5.4. Mutagenic and anti-mutagenic activity

Today it is widely known that cancer is linked essentially to mutagens and carcinogens. Among the most promising strategies to fight this disease is chemoprevention against mutagens and carcinogens. Several factors have been demonstrated in the last years as antimutagenic and anticarcinogenic which suppress and/or prevent carcinogenesis[78]. It has been accepted that plants and their products represent one of the sources possessing potential chemoprotective properties. Indeed, several secondary metabolites from medicinal plants are shown chemoprotective[79-82]. *O. compactum* essential oil and their major compounds are shown to be effective for their mutagenic and antimutagenic effects using the somatic mutation and recombination assay. Mutagenic induction was made by direct acting (urethane) and indirect (methyl methanesulfonate) mutagen. The essential oil showed a significantly strong ability to inhibit Urathane-induced mutagenesis, while the inhibition of methyl-methanesulfonate-induced mutagenesis was moderate. On the other hand, the use of the oil itself did not produce mutagenic effects. The bioguided fraction of *O. compactum* oil has identified and isolated two phenolic molecules, namely thymol and carvacrol. The antimutagenic action of the carvacrol was simultaneously effective in relation to the action of the oil, which suggested that the inhibition of the urethane by the carvacrol is responsible of the chemoprotective action of *O. compactum* essential oil[66,68].

5.5. Antifungal activity

In recent years, opportunistic fungal infections have greatly increased in patients because of the increasing population with HIV infection, cancer patients and organ or bone marrow transplant patients[69]. On the other hand, the conventional treatments for systemic mycoses have some limitations which are due to the restricted access of the population to essential medicines, the poor efficiency of the existing medicine, the high toxicity and high cost of existing medicine, and infective recidivism due to fungistatic effects[83]. Among fungal pathogen strains, we found *B. cinerea*. It is a ubiquitous pathogen fungal, which causes severe damage in fruits, vegetables and ornamental crops in pre- and post-harvest[84]. The frequent applications of the most effective fungicides resulted in the selection and predominance of the pathogen resistant strains showed that *B. cinerea* develops resistance against specific fungicides such as benzimidazoles, dicarboximides and diethofuncarband[85]. Medicinal plants have been shown as a potential source against fungal strains[86,87].

The essential oils and extracts of *O. compactum* have been tested for its antifungal effects (Table 1). The anti-fungal effect of four organic extracts (petroleum ether, methanol, hexane and chloroform) is evaluated against *Penicillium digitatum* by Fadel *et al.*[88]. Petroleum ether extract inhibited 83% of the fungal strain at a concentration of 2000 ppm, while the inhibition percentage of chloroform, hexane and methanol extracts at the same concentration were respectively 29.4%, 35.3% and 45.9%[88]. The essential oil has been tested against *B. cinerea* and is shown to be an important inhibition at low concentration IC_{50} = 35.1 ppm). This activity is attributed to the richness of the oil tested in phenolic compounds such as carvacrol and thymol[52].

5.6. Antimalaria activity

Malaria is one of the dangerous diseases in the world. Malaria is an infectious disease with periodic fever caused by the parasite *Plasmodium* and transmitted by certain kind of mosquitoes called *Anopheles*. Malaria can infect humans, birds, monkeys and other primates, reptiles and rodents. Symptoms of malaria include fever, chills, sweating and may be accompanied by other symptoms such as headache, nausea and vomiting. The human body is the nest for *Plasmodium* to breed (asexual cycle). Meanwhile, the *Anopheles* mosquito is a vector or definitive nest. There are many synthetic drugs as malaria treatment or as an antimalarial, for example, mefloquine. It is inhibiting lactate dehidrogenase that serves to compete with NADH as a cofactor on NADH binding site of the enzyme. Inhibitory lactate dehydrogenase of cofactor enzyme causes an inactive function of energy production in *Plasmodium* body[89]. *Plasmodium* has developed resistance against chemical drugs, so it is necessary to seek natural compounds from medicinal plants against this strains. In this ways, medicinal plants play a

key role[90,91]. The antimalaria activity is evaluated against *P. falciparum* using the cytotoxicity test based on the incorporation of (3H)-hypoxanthine. Petroleum ether and ethanol extracts showed low activity with inhibition concentration 50 which exceeded 100 μg/mL (IC_{50} > 100 μg/mL). While water decoction, ethyl acetate extract and essential oil gave respectively an IC_{50} = 90, IC_{50} = 33 and IC_{50} = 34 μg/mL[44].

5.7. Others biological activity of *O. compactum*

The essential oils and extracts of *O. compactum* have shown others biological activities[45,51,66,67]. The insecticidal activity of essential oils against *Spodoptera littoralis* has been reported, which induced insecticidal activity at a lethal dose 50 (LD_{50} = 0.041 mL/larva)[66]. Essential oils are also reported as antispasmodic[51]. On the other hand, ethyl acetate extract has shown a cercaricide effect against *Schistosoma haematobium*[45]. In addition, organic extracts (petroleum ether, methanol, hexane, ethyl acetate and dichloromethane) have tested for their molluscicidal activity against *Bulinus truncatus*. Ethyl acetate extracts were the most active extract (LC_{50} < 1 ppm)[67].

6. Pharmacological properties of main compounds *O. compactum*

6.1. Thymol

Thymol or 2-isopropyl-5-methylphenol is a monoterpenes that present in essential oil of *O. compactum* and other aromatic plants such as thyme. Its synthesis is derivates from cymene and isomerization of carvacrol[92]. Thymol possesses several biological effects such as antibacterial, antioxidant, antitumor, anti-inflammatory and antifungal activities[93,94]. The antibacterial effects of thymol have been evaluated by several studies[95-100] against *E. coli* and *S. typhimurium* and the MIC values against these two strains was respectively MIC = 1 and MIC = 1.2 mM[95]. The antibacterial activity of thymol against *S. typhimurium* has been also studied by Palaniappan and Holley[97] and Chauhan and Kang[98], and the MIC values were respectively MIC = 2.5 mM and MIC = 750 mM. The antifungal activity of thymol has also been investigated by some works[101-104]. In some cases, this compound has inhibited *Candida tropicalis* at very low concentrations: MIC = 39 μg/mL[101], MIC = 0.12% (v/v)[102] and MIC = 350 μg/mL[103]. The anti-inflammatory and cicatrizing effects of thymol have also proved using rodents as a model study[105].

6.2. Carvacrol

The 5-isopropyl-2-methylphenol or carvacrol is present in oregano essential oils such *O. compactum* and *Origanum vulgare*. Biochemically, the carvacrol is an isomer of thymol and its derivate is also from cymene. The yield of thymol and carvacrol is depending on the isomerization that is affected by ecological habitat of the plant[4]. Carvacrol possesses numerous pharmacological properties such as antioxidant, antimicrobial, antifungal and antitumor activities[106-109]. The antibacterial activity of carvacrol has been studied by Xu *et al.* against *E. coli* and the result showed an inhibition growth of this strain at 200 μg/mL[108]. The mechanism associating with this inhibition is related to a decreasing of membrane potential of *E. coli*. The carvacrol has also shown an antifungal effect against *Candida albicans* on in immunosuppressed rats[106]. On the other hand, Yanishlieva *et al.* have proved the antioxidant activity of carvacrol[109]. This activity was related the capacity of carvacrol to prevent lipid oxidation. In another study, Koparal *et al.* have tested and showed the antitumor potency of carvacrol against lung cancer by inhibiting cell growth in A549 cell line[107].

6.3. p-Cymene

The *p*-cymene is an alkyl-substituted aromatic hydrocarbon found in essential oils of several aromatic plants such as *O. compactum*. This molecule is a precursor of carvacrol in oregano essential oils, but it is also found in other aromatic plants essential oils such as oregano and thyme[110,111]. The *p*-cymene is a hydrophobic molecule that contains the benzene ring substituted by the methyl group such as isopropyl. It can be isomerized into two isomers forms depending on the geometric substitution; the Ortho-substitution gives the *o*-cymene, while the meta-substitution gives the *m*-cymene[112]. The *p*-cymene has shown several pharmacological properties such as antimicrobial, antioxidant and anti-inflammatory effects[113-115]. The *p*-cymene was effective for its antioxidant property by decreasing the lipid peroxidation and nitrite content by increasing in the SOD and catalase activity[114], while the anti-inflammatory activity of *p*-cymene was important when it was combined with β-cyclodextrin[115]. The *p*-cymene has an inhibitory activity against *Shigella sonnei* and *Shigella flexneri*[113].

6.4. γ-Terpinene

The γ-terpinene is hydrocarbon that has a similar structure to α-phellandrene[116]. It is found in *O. compactum* essential oils as well as in other aromatic plants essential oils such as thyme. This compound possesses a range of pharmacological properties such as antibacterial, antioxidant, antifungal, anti-inflammatory and antitumor[117]. The γ-terpinene possesses some biological properties such as antimicrobial and antioxidant activities. Indeed, Li and Liu[118] have shown the antioxidant potency of γ-terpinene. These effects were related to the protection of methyl linolenate, DNA and erythrocyte oxidation. On the other hand, Oyedemi *et al.* have shown the capacity of γ-terpinene to inhibit the growth of *L. monocytogenes* (MIC = 0.50%), *Streptococcus pyogenes* (MIC= 0.50%), *Proteus vulgaris* (MIC = 0.75%) and *E. coli* (MIC = 0.50%)[119]. The inhibition of bacterial growth was associated with cell lysis induced by the leakage of protein and lipid. In another study, Li *et al.* have shown that the γ-terpinene inhibited *Salmonella enteritidis* at MIC = MBC = 3.125%, while, these values were higher

than 50% against *S. aureus* and *E. coli*[120].

7. Conclusion

O. compactum has been used as traditional medicine in Morocco. Several parts of this species have been used in the treatment and prevention of several illnesses such as diarrhea, inflammation, and intestinal disorders. Phenols such as carvacrol and thymol are the main bioactive compounds in the essential oils of this plant. While, chemical molecules of organic extracts have poorly studied. The extracts, essential oils and their derivates have been found to possess several biological properties such as anticancer, antimicrobial and antioxidant effects. This review has presented a comprehensive overview on the phytochemistry and pharmacological applications of *O. compactum* and its main compounds. Some of oregano essential oil molecules (carvacrol, thymol, *p*-cymene and γ-terpinene) have found several applications in modern medicine. However, more bioactive molecules in oregano oils and extracts should be identified using bioguided isolation assays. In addition, clinical evaluation of the possible toxicity related these isolated compounds needs to be assessed for finding their application as biotherapeutical medicine.

Conflict of interest statement

We declare that we have no conflict of interest.

References

[1] Lahlou M. The success of natural products in drug discovery. *Pharmacol Pharm* 2013; **4**: 17-31.

[2] Kennedy DO, Wightman EL. Herbal extracts and phytochemicals: plant secondary metabolites and the enhancement of human brain function. *Adv Nutr* 2011; **2**: 32-50.

[3] Belkamel A, Bammi J, Belkamel A, Douira A. [Study of the chemical composition of the essential oil of an Iberian-Moroccan endemic: *Origanum compactum* (Benth.)]. *J Anim Plant Sci* 2013; **19**: 2880-7. French.

[4] Aboukhalid K, Lamiri A, Agacka-Mołdoch M, Doroszewska T, Douaik A, Bakha M, et al. Chemical polymorphism of *Origanum compactum* grown in all natural habitats in Morocco. *Chem Biodivers* 2016; **13**: 1126-39.

[5] Hachi M, Benkhnigue O, Hachi T, El Bouhaddioui M, Bouabadi I, Rochdi A, et al. Contribution to the ethnobotanical study of antidiabetic medicinal plants of the Central Middle Atlas region (Morocco). *Lazaroa* 2016; **37**: 135-44.

[6] Jouad H, Haloui M, Rhiouani H, El Hilaly J, Eddouks M. Ethnobotanical survey of medicinal plants used for the treatment of diabetes, cardiacandrenal diseases in the north centre region of Morocco (Fez-Boulemane). *J Ethnopharmacol* 2001; **77**: 175-82.

[7] Azizkhani M, Elizaquível P, Sánchez G, Selma MV, Aznar R. Comparative efficacy of *Zataria multiflora* Boiss., *Origanum compactum* and *Eugenia caryophyllus* essential oils against *E. coli* O157:H7, feline calicivirus and endogenous microbiota in commercial baby-leaf salads. *Int J Food Microbiol* 2013; **166**: 249-55.

[8] Sbayou H, Ababou B, Boukachabine K, Manresa A, Zerouali K, Souad A. Chemical composition and antibacterial activity of *Artemisia herba-alba* and *Mentha pulegium* essential oils. *J Life Sci* 2014; **8**: 35-41.

[9] Amakran A, Hamoudane M, Ramdan B, Ben Mehdi N, Ben Mrid Reda, Lesicki M, et al. [Study of the antioxidant, anti-glycant and photochemical properties of the essential oil of *Origanum compactum* of Tetouan]. *ScienceLib Editions Mersenne* 2014 ; **6**: 1-15. French.

[10] Ouedrhiri W, Balouiri M, Bouhdid S, Moja S, Ouazzani Chahdi F, 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.

[11] Sbayou H, Boumaza A, Hilali A, Amghar S. Antioxidant properties of *Artemisia herba-alba* Asso., *Mentha pulegium* L. and *Origanum compactum* Benth. essential oils. *J Mater Environ Sci* 2016; **7**: 2908-12.

[12] Sbayou H, Talbi H, Talha I, Amghar S, Hilali A. Evaluation of the genotoxicity of essential oil from *Origanum compactum* Benth. in human lymphocytes. *Asian J Pharm Clin Res* 2016; **9**: 1-3.

[13] Duman H, Baser KHC, Aytec Z. Two new species and a new hybrid from Anatolia. *Turk J Bot* 1998; **22**: 51-5.

[14] Laghmouchi Y, Belmehdi O, Bouyahya A, Skali Senhaji N, Abrini J. Effect of temperature, salt stress and pH on seed germination of medicinal plant *Origanum compactum*. *Biocatal Agric Biotechnol* 2017; **10**: 156-60.

[15] Aboukhalid K, Al Faiz C, Douaik A, Bakha M, Kursa K, Agacka-Mołdoch M, et al. Influence of environmental factors on essential oil variability in *Origanum compactum* Benth. growing wild in Morocco. *Chem Biodiv* 2017; doi: 10.1002/cbdv.201700158.

[16] Bouyahya A, Jamal A, Edaoudi F, Et-Touys A, Bakri Y, Dakka N. *Origanum compactum* Benth: a review on phytochemistry and pharmacological properties. *Med Arom Plant* 2016; **5**: 252.

[17] Aboukhalid K, Machon N, Lambourdière J, Abdelkrim J, Bakha M, Douaik A, et al. Analysis of genetic diversity and population structure of the endangered *Origanum compactum* from Morocco, using SSR markers: implication for conservation. *Biol Conser* 2017; **212**: 172-82.

[18] Eddouks M, Maghrani M, Lemhadri A, Ouahidi ML, Jouad H. Ethnopharmacological survey of medicinal plants used for the treatment of diabetes mellitus, hypertension and cardiac diseases in the south-east region of Morocco (Tafilalet). *J Ethnopharmacol* 2002; **82**: 97-103.

[19] El Youbi A, Ouahidi I, El Mansouri L, Daoudi A, Bousta D. Ethnopharmacological survey of plants used for immunological diseases in four regions of Morocco. *Eur J Med Plants* 2016; **13**: 1-24.

[20] Orch H, Zidane L, Douira A. Ethnobotanical study of the plants used in the treatment of the digestive diseases by the riverine population of the forest of Izarène. *Int J Recent Sci Res* 2017; **8**: 15213-19.

[21] Fakchich J, Elachouri M. Ethnobotanical survey of medicinal plants used by people in Oriental Morocco to manage various ailments. *J Ethnopharmacol* 2014; **28**: 76-87.

[22] Benlamdini N, Elhafian M, Rochdi A, Zidane L. [Study of floristic and ethnobotanical medicinal flora of the High Atlas (Haute Moulouya)]. *J Appl Biosci* 2014; **78**: 771-87. French.

[23] Ghourri M, Zidane L, Douira A. [Catalog of medicinal plants used in the treatment of renal lithiasis in the province of Tan-Tan (Morocco Saharan)]. *Int J Biol Chem Sci* 2013; **7**: 1688-700. French.

[24] Tahri N, El Basti A, Zidane L, Rochdi A, Douira A. [Ethnobotanical

study of medicinal plants in the province of Settat (Morocco)]. *Kastamonu Univ J Forest Fac* 2012; **12** : 192-208. French.

[25] Hachi M, Hachi T, Belahbib N, Dahmani J, Zidane L. Contribution to the study and floristic ethnobotany flora medicinal use at the city of Khenifra (Morocco). *Int J Innov Appl Stud* 2015; **11**: 754-70.

[26] Lahsissene H, Kahouadji A. [Ethnobotanical study of medicinal and aromatic plants in the Zaër region of Morocco]. *Phytothérapie* 2010; **8**: 202-9. French.

[27] Ennabili A, Gharnit N, El Hamdouni EL. Inventory and social interest of medicinal, aromatic and Honey-plants from Mokrisset region (NW of Morocco). *Stud Bot* 2000; **19**: 57-74.

[28] Merzouki A, Ed-derfoufi F, Molero Mesa J. Contribution to the knowledge of Rifian traditional medicine. II: Folk medicine in Ksar Lakbir district NW Morocco. *Fitoterapia* 2000; **71**: 278-307.

[29] Bouyahya A, Abrini J, Et-Touys A, Bakri Y, Dakka N. Indigenous knowledge of the use of medicinal plants in the north-west of Morocco and their biological activities. *Eur J Integr Med* 2017; **13**: 9-25.

[30] Weng CJ, Yen GC. Chemopreventive effects of dietary phytochemicals against cancer invasion and metastasis: phenolic acids, monophenol, polyphenol, and their derivatives. *Cancer Treat Rev* 2012; **38**: 76-87.

[31] Beghlal D, El Bairi K, Marmouzi I, Haddar L, Mohamed B. Phytochemical, organoleptic and ferric reducing properties of essential oil and ethanolic extract from *Pistacia lentiscus* (L.). *Asian Pac J Trop Dis* 2016; **6**: 305-15.

[32] Bouyahya A, El Moussaoui N, Abrini J, Bakri Y, Dakka N. Determination of Phenolic contents, antioxidant and antibacterial activities of strawberry tree (*Arbutus unedo* L.) leaf extracts. *Br Biotechnol J* 2016; **14**: 1-10.

[33] Bouyahya A, Abrini J, Talbaoui A, Et-Touys A, Chatoui K, Harhar H, et al. Phytochemical screening, antiradical and antibacterial activities of *Cistus crispus* from Morocco. *J Mater Environ Sci* 2017; **8**: 1560-6.

[34] Bouyahya A, Abrini J, Bakri Y, Dakka N. [Phytochemical screening and evaluation of antioxidant and antibacterial activities of *Origanum compactum* extracts]. *Phytothérapie* 2017; doi: 10.1007/s10298-017-1101-8. French.

[35] Bouyahya A, Abrini J, Et-Touys A, Lagrouh F, Dakka N, Bakri Y. [Phytochemical analysis and evaluation of the antioxidant activity of Moroccan honey samples]. *Phytothérapie* 2017; doi: 10.1007/s10298-017-1122-3. French.

[36] Aneb M, Talbaoui A, Bouyahya A, EL Boury H, Amzazi S, Benjouad A, et al. *In vitro* cytotoxic effects and antibacterial activity of Moroccan medicinal plants *Aristolochia longa* and *Lavandula multifida*. *Eur J Med Plants* 2016; **16**: 1-13.

[37] Bouyahya A, Bakri Y, Khay EO, Edaoudi F, Talbaoui A, Et-Touys A, et al. Antibacterial, antioxidant and antitumor properties of Moroccan medicinal plants: a review. *Asian Pac J Trop Dis* 2017; **7**: 57-64.

[38] 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* 2017; doi: 10.1007/s10298-017-1118-z. French.

[39] Bouyahya A, Abrini J, El-Baabou A, Bakri Y, Dakka N. Determination of phenol content and antibacterial activity of five medicinal plants ethanolic extracts from north-west of Morocco. *J Plant Pathol Microbiol* 2016; **7**: 107-11.

[40] Bouyahya A, Abrini J, Khay EO, Charfi S, Boujida N, El Harsal A, et al. *In vitro* antibacterial activity of organic extracts from north-west Moroccan medicinal plant *Myrtus communis* (L.). *Br Biotechnol J* 2016; **16**: 1-9.

[41] Et-Touys A, Fellah H, Mniouil M, Bouyahya A, Dakka N, Abdennebi EH, et al. Screening of antioxidant, antibacterial and antileishmanial activities of *Salvia officinalis* L. extracts from Morocco. *Br Microbiol Res J* 2016; **16**: 1-10.

[42] Khouchlaa A, Bouyahya A, Ait Lahcen S, Youssef B, Nadia D, Tijane M. Phytochemical screening, evaluation of antioxidant activity and litholytic effect of *Zizyphus lotus* L. extracts. *World J Pharm Res* 2017; **6**: 1354-67.

[43] Khouchlaa A, Talbaoui A, El Yahyaoui El Idrissi A, Bouyahya A, Ait Lahsen S, Kahouadji A, et al. [Determination of phenol content and evaluation of *in vitro* litholytic effects on urolithiasis of Moroccan *Zizyphus lotus* L. extract]. *Phytothérapie* 2017; doi: 10.1007/s10298-017-1106-3. French.

[44] El Babili F, Bouajila J, Souchard JP, Bertrand C, Bellvert F, Fouraste I, et al. Oregano: chemical analysis and evaluation of its antimalarial, antioxidant, and cytotoxic activities. *J Food Sci* 2011; **76**: 512-8.

[45] Lahlou M. Potential of *Origanum compactum* as a cercaricide in Morocco. *Ann Trop Med Parasitol* 2002; **96**: 587-93.

[46] Bellakhdar J, Passannanti S, Paternostro MP, Piozzi F. Constituents of *Origanum compactum*. *Plant Med* 1988; **54**: 94.

[47] Bakkali F, Averbeck S, Averbeck D, Zhiri A, Idaomar M. Cytotoxicity and gene induction by some essential oils in the yeast *Saccharomyces cerevisiae*. *Mut Res* 2005; **585**: 1-13.

[48] Bouyahya A, Bensaid M, Bakri Y, Dakka N. Phytochemistry and ethnopharmacology of *Ficus carica*. *Int J Biochem Res Rev* 2016; **14**: 1-12.

[49] Bouyahya A, Abrini J, Bakri Y, Dakka N. [Essential oils as anticancer agents: news on mode of action]. *Phytothérapie* 2016; doi: 10.1007/s10298-016-1058-z. French.

[50] Bouhdid S, Skali SN, Idaomar M, Zhiri J, Baudoux A, Abrini J. Antibacterial and antioxidant activities of *Origanum compactum* essential oil. *Afr J Biotechnol* 2008; **7**: 1563-70.

[51] Van Den Broucke CO, Lemli JA. Chemical investigation of essential oil of *Origanum compactum*. *Planta Med* 1980; **41**: 264-6.

[52] Chebli B, Achouri M, Idrissi HLM, Hmamouchi M. Chemical and antifungal activity of essential oils of seven Moroccan Labiatae against *Botrytis cinerea* Pers. *J Ethnopharmacol* 2003; **89**: 165-9.

[53] Oussalah M, Caillet S, Saucier L, Lacroix M. Inhibitory effects of selected plant essential oils on the growth of four pathogenic bacteria: *E. coli* O157:H7, *Salmonella typhimurium*, *Staphylococcus aureus* and *Listeria monocytogenes*. *Food Control* 2007; **18**: 414-20.

[54] Bakhy KO, Benlhabib A, Bighelli J, Casanova F, Tomi C. Yield and chemical variability of the essential oil isolated from aerial parts of wild *Origanum compactum* Benth. from Moroccan Western Rif. *Am J Essent Oils Nat Prod* 2014; **1**(4): 1-9.

[55] Sfeir J, Lefrançois C, Baudoux D, Derbré S, Licznar P. *In vitro* Antibacterial activity of essential oils against *Streptococcus pyogenes*. *Evid Based Complement Alternat Med* 2013; **2013**: 1-9.

[56] Mith H, Dure R, Delcenserie V, Zhiri A, Daube G, Clinquart A. Antimicrobial activities of commercial essential oils and their

components against food-borne pathogens and food spoilage bacteria. *Food Sci Nutr* 2014; **2**: 403-16.

[57] Tantaoui-Elaraki A, Ferhout I, Errifi A. Inhibition of the fungal asexual reproduction stages by three moroccan essential oils. *J Essent Oil Res* 1993; **5**: 535-45.

[58] Charai M, Mosadak M, Faid M. Chemical composition and antimicrobial activities of two aromatics plants: *Origanum majorana* and *O. compactum*. *J Essent Oil Res* 1996; **8**: 657-64.

[59] Figuérédo G, Cabassu P, Chalchat JC. Studies of Mediterranean oregano populations. VII: Chemical composition of essential oils of carvacrol-rich oregano of various origins. *J Essent Oil Res* 2006; **18**: 244-9.

[60] Jeannot V, Chahboun J, Russel D, Casabianca H. *Origanum compactum* Bentham: composition of the hydrolat aromatic fraction, comparison with the essential oil and its interest in aromatherapy. *Int J Aromather* 2003; **13**(2-3): 90-4.

[61] Bouhdid S, Abrini J, Zhiri A, Espuny MJ, Manresa A. Investigation of functional and morphological changes in *Pseudomonas aeruginosa* and *Staphylococcus aureus* cells induced by *Origanum compactum* essential oil. *J Appl Microbiol* 2009; **106**: 1558-68.

[62] Ben-Hammou F, Skali SN, Idaomar M, Abrini J. The antimicrobial effect of *Origanum compactum* essential oil nisin and their combination against *Escherichia coli* in tryptic soy broth (TSB) and in sheep natural sausage casings during storage at 25 and 7 °C. *Afr J Biotechnol* 2011; **10**: 15998-6005.

[63] Chaouki W, Meddah B, Hmamouchi M. Antiproliferative activity of *Origanum compactum* extract on lung cancer and hepatoma cells. *Arab J Med Aromat Plants* 2015; **1**(1): 44-56.

[64] Chaouki W, Leger DY, Eljastimi J, Beneytout JL, Hmamouchi M. Antiproliferative effect of extracts from *Aristolochia baetica* and *Origanum compactum* on human breast cancer cell line MCF-7. *Pharm Biol* 2010; **48**: 269-74.

[65] Mezzoug N, Elhadri A, Dallouh A, Amkiss S, Skali NS, Abrini J, et al. Investigation of the mutagenic and antimutagenic effects of *Origanum compactum* essential oil and some of its constituents. *Mutat Res* 2007; **629**: 100-10.

[66] Pavela R. Insecticidal activity of some essential oils against larvae of *Spodoptera littoralis*. *Fitoterapia* 2005; **76**: 691-6.

[67] Hmamouchi M, Lahlou M, Agoumi A. Molluscicidal activity of some Moroccan medicinal plants. *Fitoterapia* 2000; **71**: 308-14.

[68] Bouyahya A, Et-Touys A, Dakka N, Fellah H, Abrini J, Bakri Y. Antileishmanial potential of medicinal plant extracts from the north-west of Morocco. *Beni-Suef Univ J Basic Appl Sci* 2017; doi: 10.1016/j.bjbas.2017.06.003.

[69] Birben E, Sahiner UM, Sackesen C, Erzumur S, Kalavci O. Oxidative stress and antioxidant defense. *World Allergy Organ* 2012; **5**: 9-19.

[70] Beres C, Simas-Tosin Cabezudo I, Freitas SP, Lacomini M, Mellinger-Silva C, et al. Antioxidant dietary fibre recovery from Brazilian Pinot noir grape pomace. *Food Chem* 2016; **201**: 145-52.

[71] Keller JN. Interplay between oxidative damage, protein synthesis, and protein degradation in Alzheimer's disease. *J Biomed Biotechnol* 2006; **2006**: 12129.

[72] Grimsrud PA, Xie H, Griffin TJ, Bernlohr DA. Oxidative stress and covalent modification of protein with bioactive aldehydes. *J Biol Chem* 2008; **283**: 21837-41.

[73] Bouyahya A, Bakri Y, Belmehdi O, Et-Touys A, Abrini J, Dakka N. Phenolic extracts of *Centaurium erythraea* with novel antiradical, antibacterial and antileishmanial activities. *Asian Pac J Trop Dis* 2017; **7**(7): 433-9.

[74] Charai M, Faid M. Essential oils from aromatic plants (*Thymus broussonetti* Boiss *Origanum compactum* Benth and *Citrus limon* (L.) NL Burm.) as natural antioxidants for olive oil. *J Essent Oil Res* 1999; **11**: 517-21.

[75] Whiteman DC, Wilson LF. The fractions of cancer attributable to modifiable factors: a global review. *Cancer Epidemiol* 2016; **44**: 203-21.

[76] Gigelin C, Couraud S. Somatic alterations in lung cancer: do environmental factors matter? *Lung Cancer* 2016; **100**: 45-52.

[77] Berhili S, Kadiri S, Bouziane A, Aissa A, Marnouche E, Ogandaga E, et al. Associated factors with psychological distress in Moroccan breast cancer patients: a cross-sectional study. *Breast* 2016; **31**: 26-33.

[78] Basak R, Nair NK, Mittra I. Evidence for cell-free nucleic acids as continuously arising endogenous DNA mutagens. *Mutat Res* 2016; **193**: 15-21.

[79] Devi HP, Mazumder PB, Devi LP. Antioxidant and antimutagenic activity of *Curcuma caesia* Roxb. rhizome extracts. *Toxicol Rep* 2015; **2**: 423-8.

[80] Aicha N, Ines S, Mohamed BS, Ines B, Soumaya K, Kamel G, et al. Chemical composition, mutagenic and antimutagenic activities of essential oils from (Tunisian) *Artemisia campestris* and *Artemisia herba-alba*. *J Essent Oil Res* 2008; **20**: 471-7.

[81] Taherkhani M. Mutagenic and antimutagenic activities of *Artemisia absinthium* volatile oil by the bacterial reverse mutation assay in *Salmonella typhimurium* strains TA98 and TA100. *Asian Pac J Trop Dis* 2014; **4**: 840-4.

[82] Badiee P, Kordbachech P, Alborzi A, Malekhoseini S, Ramzi M, Mirhendi H, et al. Study on invasive fungal infections in immunocompromised patients to present a nuitable early diagnostic procedure. *Int J Infect Dis* 2009; **13**: 97-102.

[83] Traeder C, Kowoll S, Arastéh K. *Candida* infections in HIV positive patients 1985-2007. *Mycoses* 2008; **51**: 58-61.

[84] Elad Y, Stewart A. Microbial control of *Botrytis* spp. In: Elad Y, Williamson B, Tudzynski P, Delen N, editors. *Botrytis: biology, pathology and control*. Dordrecht: Kluwer Academic Press; 2004, p. 223-41.

[85] Leroch M, Kretschmer M, Hahn M. Fungicide resistance phenotypes of *Botrytis cinerea* isolates from commercial vineyards in South West Germany. *J Phytopathol* 2011; **159**: 63-5.

[86] Munir N, Ijaz W, Altaf I, Naz S. Evaluation of antifungal and antioxidant potential of two medicinal plants: *Aconitum heterophyllum* and *Polygonum bistorta*. *Asian Pac J Trop Biomed* 2014; **4**: 639-43.

[87] Kalidindi N, Thimmaiah NV, Jagadeesh NV, Nandeep R, Swetha S, Kalidindi B. Antifungal and antioxidant activities of organic and aqueous extracts of *Annona squamosa* Linn. leaves. *J Food Drug Anal* 2015; **23**: 795-802.

[88] Fadel F, Ben Hmamou D, Salghi R, Chebli B, Benali O, Zarrouk A, et al. Antifungal activity and anti-corrosion inhibition of *Origanum compactum* extracts. *Int J Electrochem Sci* 2013; **8**: 11019-32.

[89] Tegar M, Purnomo H. Tea leaves extracted as anti-malaria based on molecular docking plants. *Proc Environ Sci* 2013; **17**: 88-194.

[90] Omonhinmin AC, Agbara IU. Assessment of *in vivo* antioxidant properties of *Dacryodes edulis* and *Ficus exasperata* as anti-malaria plants. *Asian Pac J Trop Dis* 2013; **3**: 294-300.

[91] Omonhinmin AC, Dike IP, Agbara U. *In vivo* antioxidant assessment of two antimalarial plants-*Allamamda cathartica* and *Bixa orellana*. *Asian Pac J Trop Biomed* 2013; **3**: 388-94.

[92] Darre MJ, Kollanoor-Johny A, Venkitanarayanan K, Upadhyaya I. Practical implications of plant-derived antimicrobials in poultry diets for the control of *Salmonella* Enteritidis. *J Appl Poult Res* 2014; **23**: 340-4.

[93] Bhalla Y, Gupta VK. Jaitak V. Anticancer activity of essential oils: a review. *J Sci Food Agric* 2013; **93**: 3643-53.

[94] Deb DD, Parimala G, Saravana Devi S, Chakraborty T. Effect of thymol on peripheral blood mononuclear cell PBMC and acute promyelotic cancer cell line HL-60. *Chem Biol Interact* 2011; **193**: 97-106.

[95] Olasupo N, Fitzgerald D, Gasson M, Narbad A. Activity of natural antimicrobial compounds against *Escherichia coli* and *Salmonella enterica* serovar *Typhimurium*. *Lett Appl Microbiol* 2003; **37**: 448-51.

[96] Trombetta D, Castelli F, Sarpietro MG, Venuti V, Cristani M, Daniele C, et al. Mechanisms of antibacterial action of three monoterpenes. *Antimicrb Agents Chemother* 2005; **49**: 2474-8.

[97] Palaniappan K, Holley RA. Use of natural antimicrobials to increase antibiotic susceptibility of drug resistant bacteria. *Int J Food Microbiol* 2010; **140**: 164-8.

[98] Chauhan AK, Kang SC. Thymol disrupts the membrane integrity of *Salmonella* ser. *typhimurium in vitro* and recovers infected macrophages from oxidative stress in an *ex vivo* model. *Res Microbiol* 2014; **165**: 559-65.

[99] Du E, Gan L, Li Z, Wang W, Liu D, Guo Y. *In vitro* antibacterial activity of thymol and carvacrol and their effects on broiler chickens challenged with *Clostridium perfringens*. *J Anim Sci Biotechnol* 2015; **6**: 58.

[100] Andrade-Ochoa S, Nevárez-Moorillón GV, Sánchez-Torres LE, Villanueva-García M, Sánchez-Ramírez BE, Rodríguez-Valdez LM, et al. Quantitative structureactivity relationship of molecules constituent of different essential oils with antimycobacterial activity against *Mycobacterium tuberculosis* and *Mycobacterium bovis*. *BMC Complemt Altern Med* 2015; **15**: 332.

[101] De Castro RD, de Souza TM, Bezerra LM, Ferreira GL, Costa EM, Cavalcanti AL. Antifungal activity and mode of action of thymol and its synergism with nystatin against *Candida* species involved with infections in the oral cavity: an *in vitro* study. *BMC Complemt Altern Med* 2015; **15**: 417.

[102] Pemmaraju SC, Pruthi PA, Prasad R, Pruthi V. *Candida albicans* biofilm inhibition by synergistic action of terpenes and fluconazole. *Indian J Exp Biol* 2013; **51**: 1032-7.

[103] De Vasconcelos LC, Sampaio FC, Albuquerque Ade J, Vasconcelos LC. Cell viability of *Candida albicans* against the antifungal activity of thymol. *Braz Dent J* 2014; **25**: 277-81.

[104] Shu C, Sun L, Zhang W. Thymol has antifungal activity against *Candida albicans* during infection and maintains the innate immune response required for function of the p38 MAPK signaling pathway in *Caenorhabditis elegans*. *Immunol Res* 2016; **64**: 1013-24.

[105] Riella KR, Marinho RR, Santos JS, Pereira-Filho RN, Cardoso JC, Albuquerque-Junior RL, et al. Anti-inflammatory and cicatrizing activities of thymol, a monoterpene of the essential oil from *Lippia gracilis*, in rodents. *J Ethnopharmacol* 2012; **143**: 656-63.

[106] Chami N, Chami F, Bennis S, Trouillas J, Remmal A. Antifungal treatment with carvacrol and eugenol of oral candidiasis in immunosuppressed rats. *Braz J Infect Dis* 2004; **8**: 217-26.

[107] Koparal AT, Zeytinoglu M. Effects of carvacrol on a human non-small cell lung cancer (NSCLC) cell line, A549. *Cytotechnology* 2003; **43**: 149-54.

[108] Xu J, Zhou F, Ji BP, Pei RS, Xu N. The antibacterial mechanism of carvacrol and thymol against *Escherichia coli*. *Lett Appl Microbiol* 2008; **47**: 174-9.

[109] Yanishlieva NV, Marinova EM, Gordon MH, Raneva VG. Antioxidant activity and mechanism of action of thymol and carvacrol in two lipid systems. *Food Chem* 1999; **64**: 59-66.

[110] Eaton RW. p-Cymene catabolic pathway in *Pseudomonas putida* F1: cloning and characterization of DNA encoding conversion of p-cymene to p-cumate. *J Bacteriol* 1997; **179**: 3171-80.

[111] Juven BJ, Kanner J, Schved F, Weisslowicz H. Factors that interact with the antibacterial action of thyme essential oil and its active constituents. *J Appl Microbiol* 1994; **76**: 626-31.

[112] Romanenko EP, Tkachev AV. Identification by GC-MS of cymene isomers and 3, 7, 7-trimethylcyclohepta-1, 3, 5-triene in essential oils. *Chem Nat Compd* 2006; **42**: 699-701.

[113] Bagamboula CF, Uyttendaele M, Debevere J. Inhibitory effect of thyme and basil essential oils, carvacrol, thymol, estragol, linalool and p-cymene towards *Shigella sonnei* and *S. flexneri*. *Food Microbiol* 2004; **21**: 33-42.

[114] de Oliveira TM, de Carvalho RB, da Costa IH, de Oliveira GA, de Souza AA, de Lima SG, et al. Evaluation of p-cymene, a natural antioxidant. *Pharm Biol* 2014; **53**(3): 423-8.

[115] Quintans Jde S, Menezes PP, Santos MR, Bonjardim LR, Almeida JR, Gelain DP, et al. Improvement of p-cymene antinociceptive and anti-inflammatory effects by inclusion in β-cyclodextrin. *Phytomedicine* 2013; **20**: 436-40.

[116] Marzec KM, Reva I, Fausto R, Proniewicz LM. Comparative matrix isolation infrared spectroscopy study of 1,3- and 1,4-diene monoterpenes (aphellandrene and c-terpinene). *J Phys Chem* 2011; **115**: 4342-53.

[117] Hazzit M, Baaliouamer A, Verissimo AR, Faleiro ML, Miguel MG. Chemical composition and biological activities of Algerian *Thymus* oils. *Food Chem* 2009; **116**: 714-21.

[118] Li GX, Liu ZQ. Unusual antioxidant behavior of alpha- and gamma-terpinene in protecting methyl linoleate, DNA, and erythrocyte. *J Agric Food Chem* 2009; **57**: 3943-51.

[119] Oyedemi SO, Okoh AI, Mabinya LV, Pirochenva G, Afolayan AJ. The proposed mechanism of bactericidal action of eugenol, α-terpineol and γ-terpinene against *Listeria monocytogenes*, *Streptococcus pyogenes*, *Proteus vulgaris* and *Escherichia coli*. *Afr J Biotechnol* 2009; **8**: 1280-6.

[120] Li L, Li ZY, Yin ZQ, Wei Q, Jia RY, Zhou LJ, et al. Antibacterial activity of leaf essential oil and its constituents from *Cinnamomum longepaniculatum*. *Int J Clin Exp Med* 2014; **7**: 1721-7.