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Review article

Characterization, activities, and ethnobotanical uses of Mentha species in Morocco

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ABSTRACT

This work is a summary of the characterization, activities, and ethnobotanical surveys about aromatic and medicinal plants belonging to the genus Mentha in Morocco. The Mentha species investigated are *Mentha pulegium, Mentha spicata*, *Mentha viridis*, *Mentha suaveolens*, *Mentha longifolia*, *Mentha gattefossei*, *Mentha rotundifolia*, and *Mentha vulgare*, with *M. pulegium* being the most studied species. *M. spicata* and *M. viridis* are poorly explored even though they are daily consumed by Moroccans in tea infusions. The elucidated factors affecting the composition of Mentha essential oils are fertilization, drying conditions, mechanical impedance, NaCl stress, and Gamma irradiation. Investigation of the activities of the Mentha species showed that the main interest was dedicated to addressing the antibacterial effect towards gram+ and gram- bacteria. Essential oils of Mentha species exhibited antifungal, antiviral, antioxidant, insecticidal, licidal, niticidal, allelopathic, antidiabetic, derma-protective, and anticorrosive activities. The ethnobotanical surveys revealed that Mentha species are used in seven regions: Tafilalet, High Atlas, Fez-Boulemane, Taounat, Oujda, Ouazzane, and Rabat. By calculating the Jaccard index, the highest degree of similarity was found between Tafilalet, Rabat, and Oujda regions. The wide use of the Mentha species in Morocco highlights the high ethnobotanical value of the genus.

1. Introduction

Morocco is located in North Africa between 21°-36° N and 1°-17° W, bordered by both the Mediterranean and the Atlantic, with a surface of 710.850 km^2 and about 3400 km of coastlines. The geography of Morocco is characterized by the presence of the sea, the desert, and the mountains. The variation in altitude creates isolated zones with special ecology and climate that varies from humid to Saharan [1, 2]. We register the occurrence of about 42.000 species of plants, classified into 150 families and 940 genera [2]. The number of endemic plants in the Moroccan flora is estimated to 900 species [3]. The mountainous regions of Atlas and Rif are the most important areas for endemism [4, 5, 6]. By its biogeographical location, Morocco hosts a very rich floristic diversity as it is considered an actual plant genetic reserve [3]. Moroccan plant resources have potential use in medical, pharmaceutical, cosmetic, and agro-alimentary fields. Two-thirds of Moroccan lands can be classified as arid and semiarid with low amounts of rainfall and frequent droughts [7]. Climate change is likely to have a strong effect resulting in more aridity in Morocco. Moreover, arid conditions are accentuated by a continuously increasing crop to respond to the demographic pressure and economic development [7, 8].

The genus Mentha gathers a group of aromatic and medicinal plants from the Lamiaceae family. It is a usual taxonomic group of the Mediterranean flora, along with Olea, Salvia, and Origanum [9]. This genus consists of 20 worldwide-spread species, including *Mentha spicata*, *M. piperita*, *M. gracilis, M. pulegium*, *M. longifolia*, *M. rotundifolia*, and *M. suaveolens* [9, 10]. Many of these plants are commonly used as food seasonings or as medicine [11, 12]. On a daily basis, Moroccans consume mint tea which is an infusion of *M. spicata* and *M. viridis* leaves. Plants of the genus Mentha are a source of essential oils contained in epidermal glands, and of a variety of phenolic compounds, tannins, terpenes, terpenoids, quinones, coumarins, flavonoids, alkaloids, sterols, and saponins [6, 9, 12, 13]. The yield of essential oil, based on the dry weight for *M. pulegium* varies from 1.90% to 6.20% [6, 14, 15]. Some species of the genus Mentha are threatened of sparsity and extinction in the wild [16].

Reports indicate that the sector of ethnobotanical use of medicinal plants generated average annual earnings of 56 million Moroccan Dirhams in 2000 (the equivalent of 5,41 million Dollars), 112.40 million Moroccan Dirhams in 2003 (the equivalent of 12,16 million Dollars), and

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550 million Moroccan Dirhams in 2015 (the equivalent of 59,51 million Dollars) [17]. Researchers report that *M. pulegium* has the second economic value among all the aromatic and medicinal plants of the Taounat region (5616 km^2) after *Capparis spinosa*, with 6.12 million Moroccan Dirhams per year [4]. According to the Ministry of agriculture and marine fisheries, *M. spicata* is planted in an area of 3000 ha spread across many provinces with a production of 85000 Tons in which 5000 tons are destinated to exportation.

The species belonging to the genus Mentha are among the most important plants that produce essential oils with pharmacological,

Table 1. Characterization of Moroccan Mentha species essential oils.

Mentha species	Geographical aerea	Extraction technique	Essential oil yield (% of dry weight)	Essential oil main compounds	Reference
Mentha pulegium	Ouazzane region	Hydro-distillation	-	- Pulegone (40.98%), - Menthone (21.16%), - α-Terpineol (7.98%)	Bouyahya et al., 2017b
	Middle Atlas region	Hydro-distillation	6.20 %	**Khenifra district:** - Pulegone (81.46%), - Humulene (2.89), - Caryophyllene (1.7%)	Zekri et al., 2013
			5.90 %	**Mrirt district:** - Pulegone (71.97%), - Piperitenone (26.07%), - Chrysanthenol (0.80%)	
			5.29 %	**Azrou district:** -Pulegone (68.86%), - Piperitenone (24.81%), - Chrysanthenol (1.03%)	
	North region (Bougeddour district)	Hydro-distillation	-	- Pulegone (77.16%), - Piperitenone (6.54%), - Piperitenone oxide (1.82%)	Zantar et al., 2015
	Rif/Atlas mountains	Hydro-distillation	-	- Pulegone (66.50%), - Eucarvone (5.80%), - Caryophyllene (3.90%)	Lamiri et al., 2001
	Mrirt region	Hydro-distillation	5.2 %	- Pulegone (71.97%), - Piperitenone (26.04), - Chrysanthenol(Cis) (0.80%)	Amalich et al., 2016
	North region	Steam distillation	-	- Pulegone (33.65%), - α-Terpinenyl acetate (24.29%), - 1,8-Cineole (10.53%)	Cherrat et al., 2014
	Taourirt region	Steam distillation	2.70 %	- Pulegone (69.80%) - Piperitenone (3.10%) - Isopulegone (1.80%)	Ait Ouazzou et al., 2012
	Marrakech region/Oued Laou region	Hydro-distillation	-	- Pulegone (75.48%), - Carvone (6.66%), - Dihydro-carvone (4.64%)	Chraibi et al., 2016
Mentha spicata	Settat region	Hydro-distillation	0.72 %	- Carvone ((57.00%), - Limonene (9.14%) - Germacrene D (8.12%),	Ismaili et al., 2014
	Sais valley	Hydro-distillation	1.35 %	- Carvone (44.94%), - Dihydrocarvyl acetate (15.40%) - Limonene (8.42%),	El Hassani et al., 2009
	Sais valley	Hydro-distillation	1.20 %	- Carvone (73.01%), - Limonene (8.54%), - 1,8- Cineol (6.70%)	El Hassani et al., 2010
Mentha viridis	Rif/Atlas mountains	Hydro-distillation	-	- Carvone (60.30%), - Limonene (25.40%), - Dihydro-carvone (2.70%)	Lamiri et al., 2001
	North-west region	Hydro-distillation	-	- Carvone (37.26%), - 1.8-cinéole (11.82%), - Terpinen-4-ol (8. 72%)	Bouyahya et al., 2020
Mentha longifolia	Middle Atlas	-	-	- Piperitenone oxide (25.00%), - Piperitone oxide (24.00%)	Ghoulami et al., 2001b
Mentha suaveolens	Various regions of Morocco	Steam distillation	-	- Piperitenone oxide (56.00%), - P-cymenol-8 (20.60%), - caryophyllene (5.70%)	Oumzil et al., 2001
	Various regions of Morocco	Steam distillation	-	- Piperitone oxide (26.00%), - Piperitenone oxide (25.00%), - caryophyllene (9.80%)	Oumzil et al., 2001
	Various regions of Morocco	Steam distillation	-	- Pulegone (50.00%), - P-cymenol-8 (10.40%), - Borneol (5.60%)	Oumzil et al., 2001

antimicrobial, antifungal, and allelopathic properties [6]. Compared to *Juniperus phoenicea* and *Cyperus longus*, *M. pulegium* had a higher bactericidal effect towards a selection of pathogenic bacteria [14, 18, 19].

The ethnobotanical use of plants of the genus Mentha is common in Morocco. The first family of aromatic plants used by the local population of Ouazzane is Lamiaceae, with 40% of species belonging to the genus Mentha [20]. Traditional medicine is the first recourse for 78% of the population in Errachidia province, as well as in other regions where medicinal plants are available at low-cost [21]. Women (75%) and prescribers are the main consumers of medicinal plants [21, 22]. The preparation of traditional drugs from medicinal plants is done using different methods such as the infusion, the decoction, and the external application, while oral administration is the most used route of administration [20]. Leaves are often the part of the plant used in pharmacopeia [11, 13, 23, 24]. The common use of Mentha leaves in pharmacopeia could be due the ease and quickness of leaves harvesting. Moreover, leaves are the center of the photosynthetic phenomenon and secondary metabolites storage [20].

This work is a synthesis of the Moroccan referenced publications about characterization, activities, and ethnobotanical surveys about Mentha species.

2. Characterization of Mentha species essential oils and extracts

Table 1 represents the characterization of Mentha species essential oils in Morocco. The characterized species are; *M. pulegium*, *M. spicata*, *M. viridis, M. longifolia*, and *M. suaveolens* [4, 5, 6, 9, 18, 19, 25, 26, 27, 28, 29, 30, 31]. Figure 1 represents a picture of the Mentha species most studied in Morocco. Mentha essential oils are extracted by hydro-distillation or steam-distillation and characterized by GC-MS techniques. *M. pulegium* is the most studied species. *M. pulegium* samples are collected from Moroccan North (Ouazzane region, Bougeddour district, Rif mountains), Moroccan Est (Mrirt), and Moroccan center (Atlas Mountains, Marrakech region). *M. pulegium* characterization shows that pulegone is the main compound of the essential oil with a concentration that ranges between 33.65% and 85.44% [4, 27]. Menthone is only detected in *M. pulegium* essential oil from the Ouazzane region [18]. Even though *M. spicata* and *M. viridis* essential oils are daily consumed by Moroccans in tea infusions, these plants are poorly studied. The main compound of *M. spicata* and *M. viridis* essential oils is carvone [4, 26, 27]. Henderson's model is suitable to predict the sorption curves of the equilibrium moisture content of *M. viridis* [32]. These curves are indispensable in the pharmaceutical industry when aromatic herbs are stored and conserved.

The obtained differences in essential oil yield and chemical composition among the different samples of a Mentha species are due to the effect of parameters such as the geographical area, the season in which plant samples were collected, the distilled part of the plant, the applied distillation technique, and the occurrence of different chemotypes within the same species [4, 5, 6]. *M. pulegium* chemotypes contain either high amounts of piperitone and piperitenone or are pulegone-type [18]. Due to the high content in piperitenone and piperitone oxides, the studied Moroccan *M. longifolia* is considered as a new chemotype [4].

The number of glandular trichomes is not impacted by the mechanical impedance applied on plant roots for *M. pulegium* whereas the essential oil amount of pulegone increased 20 times [14]. Thus, the use of Olive mill wastewater as an organic amendment applied at 8 l/m^2, two months before plantation of *M. spicata* cuttings, allows an increase of 94% of the biomass yield and 17% of essential oil yield with significant changes in essential oil composition [27].

Two new heterocyclic compounds are synthesized by chemical reaction of hydroxylamine and hydrazine with piperitone oxide, the major

Figure 1. Pictures of Mentha species of Morocco; *M. piperita, M. suaveolens, M. viridis, M. rotundifolia, M. pulegium, M. longifolia, M. spicata, M. gattefossei* and *M. vulgare*.

Table 2. Different activities of Moroccan Mentha species essential oils and extracts.

Mentha Species		Activities	Used technique	Used extract	References
Mentha pulegium	**Antibacterial effect**	*Gram+*: ***Listeria monocytogenes***: IZ = 10.30 ± 0.60 mm; ***Staphylococcus aureus***: IZ = 10.70 ± 0.60 mm, *Gram -*: ***Escherichia coli***: IZ = 9.30 ± 0.60 mm; ***Salmonella senftenberg***: IZ = 9.00 ± 1 mm	Agar diffusion assay	Essential oil	Zantar et al., 2015
		Gram+: ***Staphylococcus aureus***: IZ = 10.00 ± 0.33 mm, MIC = 2.80 μl/mL; MBC = 5.60 μl/mL; *Gram-*: ***Escherichia coli***:IZ = 18.00 ± 0.40 mm, MIC = 1.40 μl/mL; MBC = 2.80 μl/mL; ***Pseudomonas aeruginosa***:IZ = 12.70 ± 3.10 mm, MIC = 11.20 μl/mL, MBC>44.80 μl/mL; ***Klebsiella pneumoniae***: IZ = 10.00 ± 0.50 mm, MIC = 5.60 μl/mL, MBC = 11.20 μl/mL	Agar diffusion and micro-dilution assays	Essential oil	Amalich et al., 2016
		Gram +: ***Staphylococcus aureus***: IZ = 21.40 ± 0.80 mm, MIC = 1 μl/mL, MBC = 30.00 μl/mL; ***Listeria monocytogenes (4b)***: IZ = 14.60 ± 0.50 mm, MIC = 1 μl/mL, MBC = 5.00 μl/mL; ***Listeria monocytogenes EGD-e***: IZ = 35.60 ± 0.60 mm, MIC = 1.00 μl/mL, MBC = 2.00 μl/mL; ***Enterococcus faecium***: MIC<0.50 μl/mL, MBC = 0.50 μl/mL; *Gram-*: ***Salmonella enteritidis***: IZ = 12.70 ± 0.10 mm, MIC = 1 μl/mL, MBC = 10 μl/ml; ***Escherichia coli O157:H7***: IZ = 12.60 ± 0.50 mm, ***Pseudomonas aeruginosa***: MIC>30.00 μl/mL, MBC>30.00 μl/mL	Agar diffusion and micro-dilution assays	Essential oil	Ait Ouazzou et al., 2012
		Gram +: ***Staphylococcus aureus MBLA***: MIC = 0.25 mg/mL, MBC = 0.25 mg/mL; ***Staphylococcus Aureus 976***: MIC = 1 mg/ml, MBC = 2.00 mg/mL; ***Staphylococcus Aureus 994***: MIC = 2 mg/mL; MBC = 2.00 mg/mL; ***Listeria Monocytogenes***: MIC = 0.50 mg/mL, MBC = 0.50 mg/mL, *Gram-*: ***Pseudomonas Aeruginosa***: MIC = 2.00 mg/mL, MBC = 2.00 mg/mL; ***Bacillus Subtilis***: MIC>2.00 mg/mL, MBC>2.00 mg/mL; ***Pseudomonas Mirabilis***: MIC = 0.50 mg/ml, MBC = 1.00 mg/mL; ***Esherichia Coli K12*** MIC = 0.50 mg/mL, MBC = 1 mg/mL	Agar micro-dilution assay	Essential oil	Bouyahya et al., 2017b
		Gram+: ***Mycobacterium smegmatis***: MIC = 0.12%; MBC = 0.12%, ***Mycobacterium aurum***: MIC = 0.03%; MBC = 0.03%	Agar micro-dilution assay	Essential oil	Chraibi et al., 2016
	Antifungal effect	***Trichophyton mentagrophytes:*** [EO] = 1.00%; ***Trichophyton rubrum***: [EO] = 0.10%; ***Epidermophyton floccosum:*** [EO] = 1.00%	Total inhibition of sporulation	Essential oil	Ismaili et al., 2014
		Rhizopus sp.: [EO] = 0.03% (growth)/[EO] = 0.10% (sporulation); **Penicillium sp.**: [EO] = 0.10% (growth)/[EO] = 0.10% (sporulation); **Aspergillus sp.**: [EO] = 0.10% (growth)/[EO] = 0.10% (sporulation);	Total inhibition of growth and sporulation	Essential oil	Amalich et al., 2016

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Table 2 (*continued*)

Mentha Species		Activities	Used technique	Used extract	References
		Penicillium italicum: Mycelium growth inhibition = 23.60% for plant powder at 10%	Mycelial growth determination	Leaves and stems powder	Askarne et al., 2012
	Antioxidant effect	**DPPH test:** scavenging activity = 88% for a concentration of EO of 60.00 µl/mL	DPPH assay	Essential oil	Zantar et al., 2015
		DPPH test: IC50 = 20.17 ± 1.88 mg/mL; **Reducing power test:** IC50 = 92.25 ± 1.32 mg/mL	DPPH and reducing power assays	Essential oil	Aljaiach et al., 2018
		DPPH test: IC50 = 321.41 ± 2.53 µg/mL; **Reducing power test:** IC50 = 58.27 ± 2.72 µg/mL	DPPH assay	Essential oil	Bouyahya et al., 2017b
	Insecticidal effect	***Tribolium castaneum*** (young adults): - Contact bioassay: IC50 = 0.05 µl/cm^2; - Fumigant bioassay: IC50 = 24.58 µl/l of air	Contact and fumigant toxicity bioassays	Essential oil	Aljaiach et al., 2018
		Sitophilus oryzae (adults): IC100 (4 days) = 2.00 µl/l of air	Fumigant toxicity bioassays	Essential oil	Zekri et al. 2013
		Mayetiola destructor: IC100 = 2.00 µl/l	Fumigant toxicity bioassays	Essential oil	Lamiri et al., 2001
	Licicidal and niticidal effect	***Pediculus capitis***: IC100 (1 h) = 3.10 µl	Micro-atmosphere and direct application	Essential oil	Lahlou et al., 2001
	Anti-leshmanial effect	***Leishmania major***: IC50 = 1.30 ± 0.50 µg/mL; ***Leishmania infantum***: IC50 = 2.00 ± 0.83 µg/mL; ***Leishmania tropica***: IC50 = 2.20 ± 0.25 µg/mL	Cell viability essay	Essential oil	Bouyahya et al., 2017b
	Allelopatic effect	***Medicago sativa***: [EO] = 2.00 mg/mL	Total inhibition of seed germination	Essential oil	Aljaiach et al., 2018
Mentha viridis	**Antibacterial effect**	*Gram+*: ***Bacillus subtilis***: MIC = 1.00 µg/ml, MBC = 1.00 µg/mL; ***Listeria monocytogenes***: MIC = 0.25 µg/mL, MBC = 0.25 µg/mL; ***Staphylococcus aureus***: MIC = 0.25 µg/mL, MBC = 0.25 µg/mL; ***Escherichia coli*** MIC = 2.00 µg/mL, MBC˃2.00 µg/mL; *Gram-*: ***Pseudomonas aeruginosa***: MIC = 0.50 µg/mL, MBC = 2.00 µg/mL; ***Proteus mirabilis***: MIC = 0.50 µg/mL, MBC = 1.00 µg/mL;	Agar diffusion and broth micro-dilution assay	Essential oil	Bouyahya et al., 2020
	Antifungal effect	Mycelium growth inhibition at [EO] = 0.75%: ***Trichophyton mentagrophytes***: 91.45 ± 3.08%, ***Trichophyton tonsurans***: 90.80 ± 2.18%, ***Trichophyton violaceum***: 90.91 ± 2.14%	Direct contact method	Essential oil	Bouyahya et al., 2020
	Antioxidant effect	DPPH: IC50 = 80.45 ± 1.86 µg/mL, FRAP: IC50 = 101.78 ± 3.14 µg/mL, ABTS: IC50 = 139.59 ± 3.12 µg/mL	DPPH, FRAP, and ABTS assays	Essential oil	Bouyahya et al., 2020
	Antidiabetic effect	α-Amylase: IC50 = 101.72 ± 1.86 µg/mL, α-Glucosidase: IC50 = 86.93 ± 2.43 µg/mL	α-Amylase and α-Glucosidase inhibitory assays	Essential oil	Bouyahya et al., 2020
	Derma-protective effect	Tyrosinase: IC50 = 55.13 ± 1.01 µg/mL, elastase: 114.24 ± 1.22 µg/mL	Tyrosinase and elastase inhibitory assay	Essential oil	Bouyahya et al., 2020
Mentha Longifolia	**Antiviral effect**	***HIV virus***: inhibition of 50% of reverse transcriptase at [Extract] = 100 µg/mL	Cell viability assay	Extract in organic solvents and H_2O	Amzazi et al., 2003
Mentha suaveolens	**Antibacterial effect**	*Gram+*: ***Staphylococcus aureus***, ***Staphylococcus simulans***, ***Staphylococcus saprophyticus*** and ***Enterococcus*** sp and ***Bacillus anthracis***: MICs ranging between 0.69 and 5.55 ppm, *Gram-*: ***Escherichia coli***, ***Klebsiella pneumoniae***, ***Pseudomonas***	Agar diffusion method and microtitration method	Essential oil	Oumzil et al., 2002

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Table 2 (*continued*)

Mentha Species		Activities	Used technique	Used extract	References
		aeruginosa, ***Pseudomonas fluorescens***, ***Proteus mirabilis***, ***Enterobacter avium***, ***Citrobacter freundii***: MICs ranging between 0.34 and 5.55 ppm			
	Antifungal effect	***Candida albicans***: MICs ranging between 0.34 and 5.55 ppm; ***Candida glabrata*** MICs ranging between 0.69 and 2.77 ppm	Agar diffusion method	Essential oil	Oumzil et al., 2002
		Trichophyton mentagrophytes: [EO] = 0.10%; ***Trichophyton rubrum***: [EO] = 1.00%; ***Trichophyton floccosum***: [EO] = 1.00%	Total inhibition of growth	Essential oil	Ismaili et al., 2014

IZ = Inhibition Zone, MIC = Minimal Inhibitory Concentration, MBC = Minimal Bactericidal Concentration, IC50 = half maximal inhibitory concentration, EO = Essential Oil.

compound of *M. suaveolens* essential oil [33]. Other researchers demonstrated that low dose gamma irradiation is efficient to decontaminate *M. piperita* contaminated with *Escherichia coli* [34]. The amount of phenolic material in the plant increases after the irradiation. Saline stress simulated by different NaCl concentrations (50–150 mM) affects growth, mineral content and essential oil yield and composition for *M. suaveolens* subsp. Timija [16]. The results show that increasing NaCl concentration up to 150 mM significantly reduces the fresh and dry plant biomass by 47.55% and 69.32%, respectively. The Essential oil yield decreases by 38.90% and 50.60% at 100 and 150 mM of NaCl, respectively. Abundance of menthone in the essential oil was affected by salt stress.

3. Activities of Mentha species essential oils and extracts

3.1. Antibacterial and antiviral activity

Table 2 represents the activities of the different Mentha species. The study of the activity of Mentha species extracts showed that a main interest has been dedicated to investigate antibacterial activity of mint extracts towards gram+ and gram- bacteria that are a source of multiple diseases in Morocco and worldwide. *M. pulegium* is the most studied species for its antibacterial activity. Essential oils of *M. pulegium*, *M. viridis*, *M. longifolia*, and *M. suaveolens* are performing antibacterial effects towards gram+ and gram- bacteria [10, 18, 25, 30, 31, 35]. Gram + bacteria are more susceptible than gram- bacteria to the antimicrobial activity of *M. pulegium* essential oil, considering the MBC/MIC ratios (MBC = Minimal Bactericidal Concentration, MIC = Minimal Inhibitory Concentration) [10, 15]. This result could be explained by the characteristics and structure of the cell envelope of the gram- bacteria [15]. *M. pulegium* essential oil is more effective than amoxicillin toward *Escherichia coli*, *Pseudomonas aeruginosa*, and *Klebsiella pneumoniae,* but less effective towards those same strains in comparison with the antibiotic imipenem in agar medium [10]. The essential oil of *M. pulegium* combined with heat was highly effective, as up to 5 log10 cell cycle reductions were obtained, due to heat making cells more sensitive to the bactericidal activity of the essential oil constituents, mainly sesquiterpenes [15]. Gamma irradiation of *M. pulegium* plant significantly affects the antibacterial activity of its essential oil especially towards gram- bacteria [31]. *M. viridis* essential oil was more performing than erythromycin and chloramphenicol against a range of gram+ and gram- bacteria, with gram + bacteria more inhibited than gram- bacteria [35]. Ethyl acetate extract from *M. longifolia* inhibited to 50% the activity of HIV-1 reverse transcriptase [36].

3.2. Antifungal activity

The antifungal activity of the essential oil of Mentha species is less studied compared to the antibacterial activity. This statement could be explained by the fact that antifungal activity is more delicate to investigate. The investigation of the antifungal effect of *M. pulegium* on strains causing eczematic sur-infections demonstrated that the plant essential oil has significant inhibitory activity on the three fungi *Trichophyton mentagrophytes*, *Trichophyton rubrum*, and *Epidermophyton floccosum* [37]. The essential oil of *M. pulegium* is highly effective towards *Rhisosporus* sp with a total inhibition of mycelial growth and sporulation at only 0.03% and 0.10% of the essential oil concentration, respectively [10]. The antifungal activity of Mentha essential oil is mainly due to the presence of terpenes and terpenoids [13, 30]. In *M. pulegium* Essential oil, highly active oxygenated monoterpenes are found at high concentrations [29]. Pulegone is the most effective component of *M. suaveolens* essential oil, against *Candida albicans* and *Candida glabrata* [30]. *Mentha viridis* essential oil inhibited up to 90% of mycelial growth of pathogenic *Trichophyton mentagrophytes*, *Trichophyton tonsurans*, and *Trichophyton violaceum* [35], meanwhile essential oil of *M. suaveolens* caused a total inhibition of growth of *Trichophyton rubrum* at only 0,10% of essential oil in experimental medium [37]. Nevertheless, further in vivo tests are required to confirm antibacterial, antiviral, and antifungal activities of Mentha essential oils reported in in vitro tests [35].

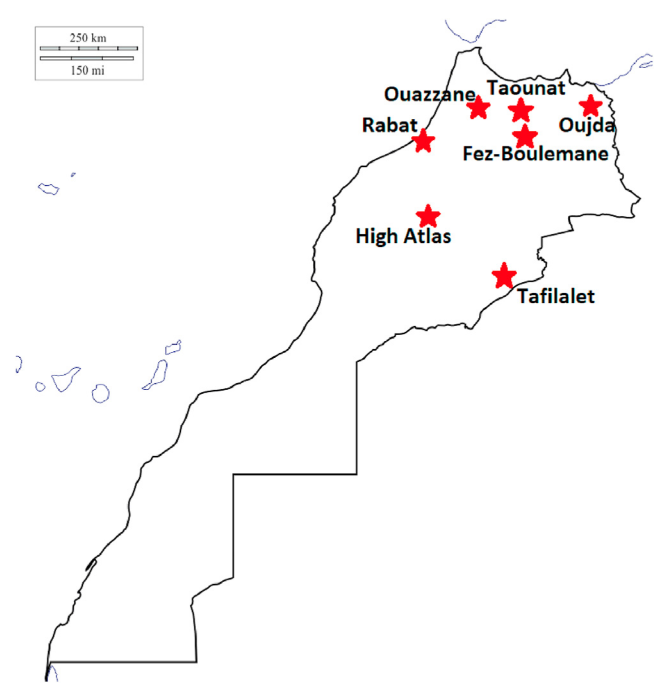

Figure 2. Location of the areas of ethno-botanical studies concerning Mentha species in Morocco.

Table 3. Ethnobotanical uses of Mentha species in different areas of Morocco.

Region	Mentha species	Vernacular name	Used parts of the plant	Uses	Route of administration	References
Tafilalet region	*Mentha pulegium*	Fliou	Aerial parts	Diabetes, respiratory diseases, gastrointestinal disorders, hypertension, cardiac diseases, rheumatism, migraine, infertility, pains, fever, obesity, nervous disorders	Decoction, Infusion, external application	Edouks et al., 2002; Tahraoui et al., 2007; Eddouks et al., 2016; El Gharbaoui et al., 2017; Ziyyat et al., 1997
	Mentha spicata	Liqama, Naanaa	Leaves and stems	Hypertension, cardiac diseases	-	Eddouks et al., 2002; Tahraoui et al., 2007; El Gharboui et al., 2017
Rabat region	*Mentha pulegium*	Fliou	Leaves	gastrointestinal disorders (carminative), musculo-skeletal Illnesses (antipasmodic)	Essential oil different uses	Lahlou et al., 2001
	Mentha spicata	Naanaa	Leaves	Gastrointestinal disorders, skin pathologies, burns	External application (Poultice of essential oil or fresh leaf paste mixed with olive oil)	Salhi et al., 2019
High Atlas region	*Mentha pulegium*	Fliou	Leaves	Respiratory diseases, gastrointestinal disorders, gynecological and endocrinological injuries	Decoction, oral ingestion, external application, inhalant	Teixidor-toneu et al., 2016
	Mentha suaveolens	Timija	Leaves	Respiratory diseases, gastrointestinal disorders, musculo-skeletal illnesses, oto-laryngological and pediatric illnesses	Decoction, oral ingestion, inhalant, external application	Teixidor-toneu et al., 2016
	Mentha gattefossei Maire	Tafleyout	Leaves	General health	Decoction	Teixidor-toneu et al., 2016
Ouazzane region	*Mentha pulegium* (L.) Hudson	-	-	Respiratory diseases	-	Gonzale-Tejero et al., 2008
	Mentha rotundifolia L. subsp. *Cyprica* (H. Braun) R. Harley	-	-	Skin pathologies	-	Gonzale-Tejero et al., 2008
Oujda region	*Mentha pulegium*	Fliou	Leaves, whole plant, flowers	Respiratory disorders, Gastrointestinal disorders, genito-urinary diseases, infectious and parasitic diseases, hemoroids, undefined symptoms (headache, flatulence)	Decoction, infusion, maceration, oral ingestion, external application, inhalant	El Gharbaoui et al., 2017; Fakchich et al., 2014
	Mentha spicata	Liqama, Naanaa		Gastrointestinal disorders, hemorrhoids, complications of pregnancy and child birth, infectious and parasitic diseases, burns, undefined symptoms (headache, thirst, tonic)	-	El Gharbaoui et al., 2017
	Mentha suaveolens	Tamarsad	Leaves, whole plant	Diabetes, digestive disorders, allergies	Decoction, infusion, oral ingestion, inhalant, external application	Fakchich et al., 2014
	Mentha viridis	Naanaa	Leaves, whole plant, flowers	Respiratory disorders, renal pathologies, skin pathologies	Decoction, infusion, oral ingestion, external application, inhalant	Fakchich et al., 2014
Taounat region	*Mentha pulegium*	Fliou	Leaves, stems, essential oil	Respiratory disorders, skin pathologies	Infusion, oral ingestion, external application	El Hilaly et al., 2003
	Mentha rotundifolia	Msisetru	Leaves, stems	Respiratory disorders, digestive disorders	Decoction, oral ingestion	El Hilaly et al., 2003
	Mentha viridis	Naanaa	Leaves, stems	Headache, tiredness	Infusion, oral ingestion	El Hilaly et al., 2003
Fez-Boulemane region	*Mentha pulegium* L.	Fliou	Aerial parts	Diabetes	-	Jouad et al., 2001
	Mentha vulgare L.	Merriwa, Merriwta	Aerial parts	Diabetes	-	Jouad et al., 2001
	Mentha viridis L.	Liqama, Naanaa	Leaves	Hypertention	-	Jouad et al., 2001

3.3. Antioxidant activity

M. viridis has a higher antioxidant activity (IC50 = 80.45 ± 1.86 μg/mL) compared to *M. pulegium (*IC50 = 20.17 ± 1.88 mg/mL) [31, 35, 38]. This statement highlights the value of *M. viridis* as an antioxidant plant. Aljaiash et al., 2018 demonstrated that drying *M. pulegium* plants at 50 °C is recommended to enhance the antioxidant activity of its essential oil. The antioxidant activity of the essential oil of *M. pulegium* is concentration-dependent and it is attributed to its oxygenated sesquiterpenes [15]. The plant essential oil showed higher antioxidant

Table 4. Jaccard index calculation.

	Tafilatet region	Rabat region	High Atlas region	Ouazzane region	Oujda region	Taounate region	Fez-Boulemane region
Tafilatet region		100	25	33.3	50	25	25
Rabat region	100		50	50	100	50	50
High Atlas region	25	50		25	40	20	20
Ouazzane region	33.3	50	25		20	33.3	25
Oujda region	50	100	40	20		40	40
Taounate region	25	50	20	33.3	40		50
Fez-Boulemane region	25	50	20	25	40	50	

activities with DPPH and β-carotene method than with the reductive potential method. Gamma irradiation of *M. pulegium* doesn't affect the antioxidant potency of its essential oil up to a dose of 30 kGy of irradiation [31].

3.4. Insecticidal, licidal, niticidal and allelopathic activities

The insecticidal activity of the essential oil could be due to the effect of some of its major constituents, the effect of its minor constituents or the synergistic effect of several constituents [6]. An in vitro study reports that *M. pulegium* was the most insecticidal species towards eggs and adults of *Mayetiola destructor* which is the major pest of wheat in Morocco, compared to other seventeen species [4]. These authors report that there is a prominent difference between the level of mortality obtained with *M. pulegium* essential oil and that obtained with other essential oils from other plants, including *M. viridis* that has low insecticidal activity. The essential oil from *M. pulegium* has the most effective licicidal and niticidal effects toward the head louse, *Pediculus capitis*, in comparison with *Thymus brousyonettii* (Lamiaceae), *Chenofiodium ambrorioides* (Chenopodiaceae), and *Ruta chalepensis* (Rutaceae) [28]. Essential oils are natural alternative products to synthetic insecticides due to their physicochemical properties of being biodegradable and volatile so that there is no risk of residues deposit on treated crops [6]. Moreover, essential oils are less toxic to mammals since they act on octopaminergic sites in parasitic insects. *M. pulegium* essential oil has the most anti-leishmanial effect against *Leishmania major*. *M. pulegium* essential oil caused an inhibition of 100% of the germination of *Medicago sativa* seeds [20, 38]. The allelopathic activity of *M. pulegium* essential oil towards *Medicago sativa* seeds germination wasn't affected by the plant drying process before hydro-distillation [38]. These results approve that Mentha essential oils are a valuable source of bioactive molecules with different potential applications in agricultural and medical fields.

3.5. Antidiabetic and derma-protective activities

In vitro inhibition of enzymes involved in degradation of carbohydrates shows that *M. viridis* essential oil exhibits important inhibitory effect against α-Amylase (IC50 $= 101.72 \pm 1.86$ μg/mL) and α-Glucosidase (IC50 $= 86.93 \pm 2.43$ μg/mL) [20]. Moreover, these authors reported a derma-protective activity of *M. viridis* essential oil due to inhibition of the enzymes tyrosinase (IC50 $= 55.13 \pm 1.01$ μg/mL) and elastase (IC50 $= 114.24 \pm 1.22$ μg/mL).

3.6. Anticorrosive activity

A study demonstrated that the derivatives of carvone, the mean compound of *M. spicata* essential oil, reduced the corrosion of steel in HCl medium [39].

4. Ethnobotanical surveys

The ethnobotanical surveys that tackle the use of Mentha species in Morocco reveal that there are seven studied regions: Tafilalet, High Atlas, Fez-Boulemane, Taounat, Oujda, Ouazzane, and Rabat (Figure 2). Leaves are the most used part of the mint plants in the treatment of illnesses by locals. Herbalists prescribe leaves as plant parts in 43%, bark in 18%, and roots in 18% [24]. *M. pulegium* is the most used Mentha species by the Moroccan population in pharmacopeia (Table 3). This plant is widely administered by locals in regions of Tafilalet, High Atlas, Fez- Boulemane, Taounat, Oujda, Ouazzane, and Rabat. In Tafilalet region, *M. pulegium* is the second most known plant (Rank Order Priority = 51%), after *Origanium vulgare* [11]. *M. pulegium* is used by the population for diabetes, hypertension, cardiac diseases, rheumatism, migraine, respiratory diseases, gastrointestinal disorders, pains, fever, nervous disorders, obesity, musculoskeletal illnesses, gynecological and endocrinological injuries, genito-urinary diseases, and skin pathologies [2, 9, 11, 12, 21, 22, 23, 28, 40, 41, 42].

In addition to pharmacopeia uses presented in Table 3, *M. spicata* and *M. viridis* are widely consumed in Morocco to make tea infusion. *M. spicata* is recommended for hypertension, cardiac diseases, gastrointestinal disorders, infectious and parasitic diseases, complications of pregnancy and childbirth, skin pathologies, burns, and undefined symptoms (headache, thirst, tonic) [12, 21, 23, 24]. *M. viridis* is especially used to heal respiratory disorders, renal pathologies, hypertension, skin pathologies, headache, and tiredness [2, 4, 41]. When *M. pulegium*, *M. spicata*, and *M. viridis* are widely used in all Morocco, the other Mentha species are used only in limited zones. *M. suaveolens* is administered by the populations of High Atlas and Oujda regions [2, 42]. The main routes of administration of the plant are decoction, oral ingestion, inhalant, and external application (Table 3). In High Atlas, *M. suaveolens* is mainly used for respiratory diseases, gastrointestinal disorders, musculoskeletal illnesses, otolaryngological and pediatric illnesses, while in the Oujda region it is used for diabetes, digestive disorders, and allergies. *M. rotundifolia* is recommended in the Ouazzane region for skin pathologies, while it is used in the Taounat region for respiratory and digestive disorders [9, 40]. In High Atlas, *M. gattefossei* is administered as a decoction, for general health [42], while *M. vulgare* is used in the Fez-Boulemane region for diabetes [41]. The difference in use of the same plant depending on the region must be linked to the cultural heritage of the medicinal plants' use in the region. It could also be explained by factors such as degradation and deforestation that affect the availability of the plant to the local population [20].

The Jaccard index determines the percentage of similarity amongst different areas. Jaccard index compares the samples two at a time according to species with consideration of their presence or absence in each sample [9]. The formula to calculate Jaccard index is:

$$\text{Index of Jaccard} = \left[\frac{C}{A + B - C} \times 100\right]$$

with A is the number of species of sample A, B the number of species of sample B, and C is the number of species common to A and B.

As shown in Table 4, the highest degree of similarity was found between Tafilalet, Rabat, and Oujda regions where *M. pulegium* and *M. spicata* are the plants of the genus Mentha the most used by the population. This could be explained by similarities in ethnobotanical habits and the profile of medicinal plants cultivated in the three zones.

Overall, the different zones presented an index of similarity close to each other. This result demonstrates a homogeneity in the use of Mentha species in Morocco and highlights the ethnobotanical value of the genus. By calculating the Jaccard similarity index, it was reported that the ethnobotanical use of medicinal plants belonging to multiple genera is different amongst Moroccan zones, and in comparison, with the neighboring countries, Mauritania, Algeria and Spain [11].

In Tafilalet, Oujda and, North-west of Morocco, women use more phytotherapy (61–76%) than men (23–39%) [2, 20, 23]. This result must be explained by the fact that women are more involved in traditional knowledge of medicinal plants use and are more often at home during the hours of the surveys [11, 41]. The level of education is firmly correlated with the use of medicinal plants [11]. Moreover, older people practice phytotherapy more often compared to younger people [20].

The effectiveness of a medicinal plant is affected by its route of administration. A synergetic effect between the essential oil of *M. pulegium* and honey was reported [42]. Frequently, locals administrate more than one plant in each treatment [40]. 10% of type 1 diabetic patients are using medicinal plants in addition to insulin treatment, 25% of type 2 diabetic patients use only medicinal plants, whereas 75% use phytotherapy associated with medical drugs [23]. Traditional phytotherapy is widely practiced in Morocco, however, medical diagnosis and medicinal plants prescription continue to be a critical problem since herbalists assume this function, even though this is not their specialty. Another issue is the packaging of medicinal plants by the herbalists undergoes exposition to sun, to dust, and to different contaminants which damages the plant and reduces its efficacity [24]. The Moroccan Anti-poison and pharmacology Center published in 2012 that twelve people passed away because of an inappropriate use of a medicinal plant. The main intoxication cause is the administration of contaminated plants [31]. The toxicity of the medicinal plants used in the north-east of Morocco is evaluated and it is reported that the species *M. pulegium* and *M. spicata* use can show adverse effects such as changes in reproductive performance and fetotoxicity for *M. pulegium* and abdominal muscle twitches, hyper-urination, convulsions, and lung tissue degeneration for *M. spicata* [43]. Despite these issues, phytotherapy is actually one main health care in Morocco since its efficacity is well proven [22]. The challenge for Moroccan society is to implement guidelines to safeguard medicinal and aromatic plants and supervise their local use by the population [17].

5. Conclusion

Moroccan researchers have investigated the characteristics, the activities and the ethnobotanical use of the plants of the genus Mentha in Morocco. Mint essential oils and solvent extracts exhibit antibacterial, antiviral, antifungal, antioxidant, insecticidal, licidal, niticidal, allelopathic, antidiabetic, derma-protective, and anticorrosive activities. The highest degree of similarity in ethnobotanical uses is found between Tafilalet, Rabat, and Oujda regions where *M. pulegium* and *Mentha spicata* are the plants of the genus Mentha the most used by the population. Jaccard index calculation demonstrates a homogeneity in the use of Mentha species in Morocco and highlights the ethnobotanical value of the genus. The Mentha species are used differently in the various regions by the locals.

The plants of the genus Mentha are widely used in Morocco, nevertheless, the number of studies tackling their characterization and valorization is limited. Other Primordial factors that affect essential oil content, such as seasoning, heavy metal presence, soil and plant microbial interactions, phytopathogen, and insects presence, have to be addressed. Moreover, more applied research has to be developed about the potential use of Mentha extracts and essential oils in industrial fields of pharmaceutical, food, agronomic, cosmetic, sanitary, and perfume industries.

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