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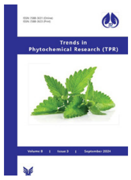

Original Research Article

Chemical polymorphism of *Thymus atlanticus*, an endemic plant of Morocco

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ABSTRACT

Thymus atlanticus is an aromatic and medicinal plant endemic to Morocco characterized by important morphological polymorphism. The objective of this study is to determine the chemical polymorphism of *T.atlanticus* collected in different regions of Morocco. The analysis of essential oils (EOs) was carried out by gas chromatography-mass spectrometry (GC-MS). In total, 88 components were identified, among them, eleven compounds are major: *o*-Cymene, γ-terpinene, thymol methyl ether, geraniol, thymol, *p*-cymen-7-ol, carvacrol, nerolidol, shyobunol, α-terpinyl acetate, and linalool. We determined eight chemotypes: Thymol (2.0%) and thymol methyl ether (19.0%) chemotype, carvacrol (31.7%) and thymol (22.4%) chemotype, geraniol (33.8%) and carvacrol (23.3%) chemotype. The sites, Oukaimeden, Tizi n'Tichka and Tizi n'Ait Imi characterized by a single majority compound for each; nerolidol (37.0%) at Oukaimeden, carvacrol (28.7%) for Tizi n'Tichka and shyobunol (26.3%) for Tizi n'Ait Imi. However, Saghro EO characterized by several major compounds; γ-terpinene (19.4%), *p*-cymene-7-ol (16.0%), *o*-cymene (15.9%), thymol (13.1). On the other hand, Tizi n'Talghemt characterized by several major compounds; linalool (28.2%), α-terpinyl acetate (28.7).Asteraceae, Rutaceae, and Fabaceae. The health-promoting properties of coumarins and their derivatives were found to be extensive. Many studies have reported their antioxidant, anti-inflammatory, anticancer, antibacterial, and antifungal activities. The compounds have shown potential in protecting against cardiovascular diseases, neurodegenerative disorders, diabetes, and obesity. Understanding the structure-activity relationships of these compounds is crucial for further research and development in this area.

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1. Introduction

Thymus species are well recognized as medicinal plants due to their pharmacological and biological properties (Hashemi-Moghaddam et al., 2015; Yeddes et al., 2023; Mashkani et al., 2024). These properties primarily depend on their chemical constituents, which are largely attributed to their structural analogs, specifically thymol and carvacrol (Hajimehdipoor et al., 2010; Tohidi et al., 2017). The main components of *Thymus* essential oil (EO) include thymol (30.0%), carvacrol (20.0%), *p*-cymol, linalool, α-pinene and γ-terpene (Wichtl, 1994).

Knowledge of the chemical composition of essential oils is a crucial quality criterion for their marketing and plays a significant role in their development. However, several factors, including climatic and geographical conditions, as well as the growth stage of the harvested plants, can significantly impact the yield of essential oils, their composition, and their biological properties. Therefore, studies examining the chemical variability of essential oils in relation to environmental factors offer valuable insights into the determinants of their chemical polymorphism (Zouari et al., 2012). Similarly, the chemical profile of the EOs of a specific plant species may exhibit variations in chemotype due to ecological and geographical factors, the age of the plant, and the timing of the harvest (Petretto et al., 2016). Such chemotype variations significantly influence the biological activity of EO.

The aim of this study is to provide information on the variation of volatile matter in *T. atlanticus* collected from eight different localities in Morocco, while also examining the effect of environmental parameters on

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the chemical polymorphism of *T. atlanticus*.

2. Experimental

2.1. Plant material

Samples of *T. atlanticus* growing in the wild were collected during flowering from eight sites in different regions of Morocco in June-July2022 (Fig.1). Plant specimens have been taxonomically identified by Bakali Homrani Abdelmonaim of the National Institute of Agronomic Research (INRA). Reference specimens from each locality are kept in the herbarium of the National Institute for Agronomic Research (INRA). The geographical coordinates (altitude, latitude and longitude) were noted (GPS) (Table 1).

2.2. Extraction of essential oil

One hundred grams of dried aerial parts of *T. atlanticus* was submerged in 1.0 L of distilled water and subjected to 3 hours of hydrodistillation using a Clevenger-type apparatus are commended by the European Pharmacopoeia. The obtained volatile oil was separated and stored at +4 °C until analyzed.

2.3. Essential oil analysis

The essential oils were analyzed with a Perkin-ElmerTurbo Mass detector (quadrupole), directly coupled to a Perkin-Elmer Autosystem XL, equipped with a fused-silica capillary column (column 30.0 m x 250 µm mmi.d., film thickness 0.25 µm), Rtx-1(polydimethyl siloxane). Carrier gas: helium at 1 mL/min; split:20:1; Initial temp 60 °C for 3 min, 1 °C/min to 80 °C, 5 °C/min to 280 °C, injection volume: 1 µL, solvent delay: 4.25 min; ion source temperature: 200 °C; energy ionization: 70 eV; electron ionization mass spectra were acquired over the mass range 50 to 550 Da.

2.4. Data analysis

The correlation between the main compounds of *T. atlanticus* and environmental parameters, principal component analysis (PCA) and cluster analysis were performed by PAST 4.0.

3. Results and Discussion

3.1. Variation of essential oils among populations

Thymus atlanticus was characterized by variability in essential oil yield, with the highest yield recorded in the Saghro region at 3.82%, followed by Tizi n'Talghemt and Bou-Naceur, which have yields of 1.67% and 1.02%, respectively (Table 2). However, the yields from the other populations are below 1.0%. The EO chemical characterization of eight populations of *T. atlanticus* was conducted using gas chromatography-mass spectrometry (GC-MS), resulting in the identification of 88 compounds (Table 2). The analysis of the chemical composition of the EOs of *T. atlanticus* revealed that the various sites are characterized by a low yield of monoterpene hydrocarbons, with the exceptions of Bou-Naceur (13.9%) and Saghro (42.3%) regions. However, all sites were rich in oxygenated monoterpenes, which account for 82.7% of the total composition. The yield of sesquiterpene hydrocarbons does not exceed 16.7%. Similarly, the levels of oxygenated sesquiterpenes were low across different localities, except for Oukaimeden (40.6%) and Tizi n'Ait Imi (39.7%) regions. GC-MS analysis identified eleven major compounds: *o*-Cymene, γ-terpinene, thymol methyl ether, geraniol, thymol, *p*-cymene-7-ol, carvacrol, nerolidol, linalool, α-terpinyl acetate, and shyobunol (Table 3). These major constituents could be considered characteristic markers of the chemotype of the studied plant. Notably, Aghenbo N'Orz was distinguished by the abundance of thymol (29.9%) and thymol methyl ether (19.0%). Similarly, Bou-Naceur was rich in thymol (22.4%) and carvacrol (31.7%), followed by *o*-cymene and γ-terpinene, which account for 12.5% and 13.9%, respectively. However, Tireghist EO was characterized by two major compounds, namely geraniol and carvacrol, with percentages of 33.8% and 23.3%, respectively. Oukaimeden, Tizi n'Tichka, and Tizi n'Ait Imi each EOs feature a single major compound, namely nerolidol (37.0%) in Oukaimeden; carvacrol (28.7%) in Tizi n'Tichka; and shyobunol (26.3%) in Tizi n'Ait Imi. However, Saghro EO was characterized by several predominant compounds, namely γ-terpinene (19.4%), *p*-cymene-7-ol (16.0%), *o*-cymene (15.9%), and thymol (13.1%). Additionally, Tizi n'Talghemt was characterized by several major compounds, including linalool (28.2%) and α-terpinyl acetate (28.7%).

3.2. Correlation

The correlation between the major compounds of *T. atlanticus* shows that *o*-cymene positively correlated with γ-terpinene and *p*-cymen-7-ol with correlation coefficients of $R = 0.997$ and $R = 0.755$, respectively (see Table 4). The same γ-terpinene is positively correlated with *p*-cymen-7-ol ($R = 0.78$). Thymol is positively correlated with thymol methyl ether and negatively with nerolidol. However, linalool is totally correlated with α-terpinyl acetate. In order to determine the effect of environmental parameters on the chemical polymorphism of *T. atlanticus*, the correlation between the main compounds of *T. atlanticus* and the environmental parameters including altitude, precipitation and temperature, was carried out. As seen in Table 4, the main compounds *o*-cymene, γ-terpinene and *p*-cymen-7-ol show a negative correlation with precipitation. However, they are positively correlated with temperature. Further more, linalool and α-terpinyl acetate are negatively correlated with altitude.

3.3. Principal component analysis

In Fig. 2, the relationships between major compounds in EOs and their ratios across different areas of plant distribution (in various localities) are illustrated as a principal component analysis (PCA) scatter plot. In this analysis, only the first two principal components (PCs) were considered. PC1 represented positive contributions

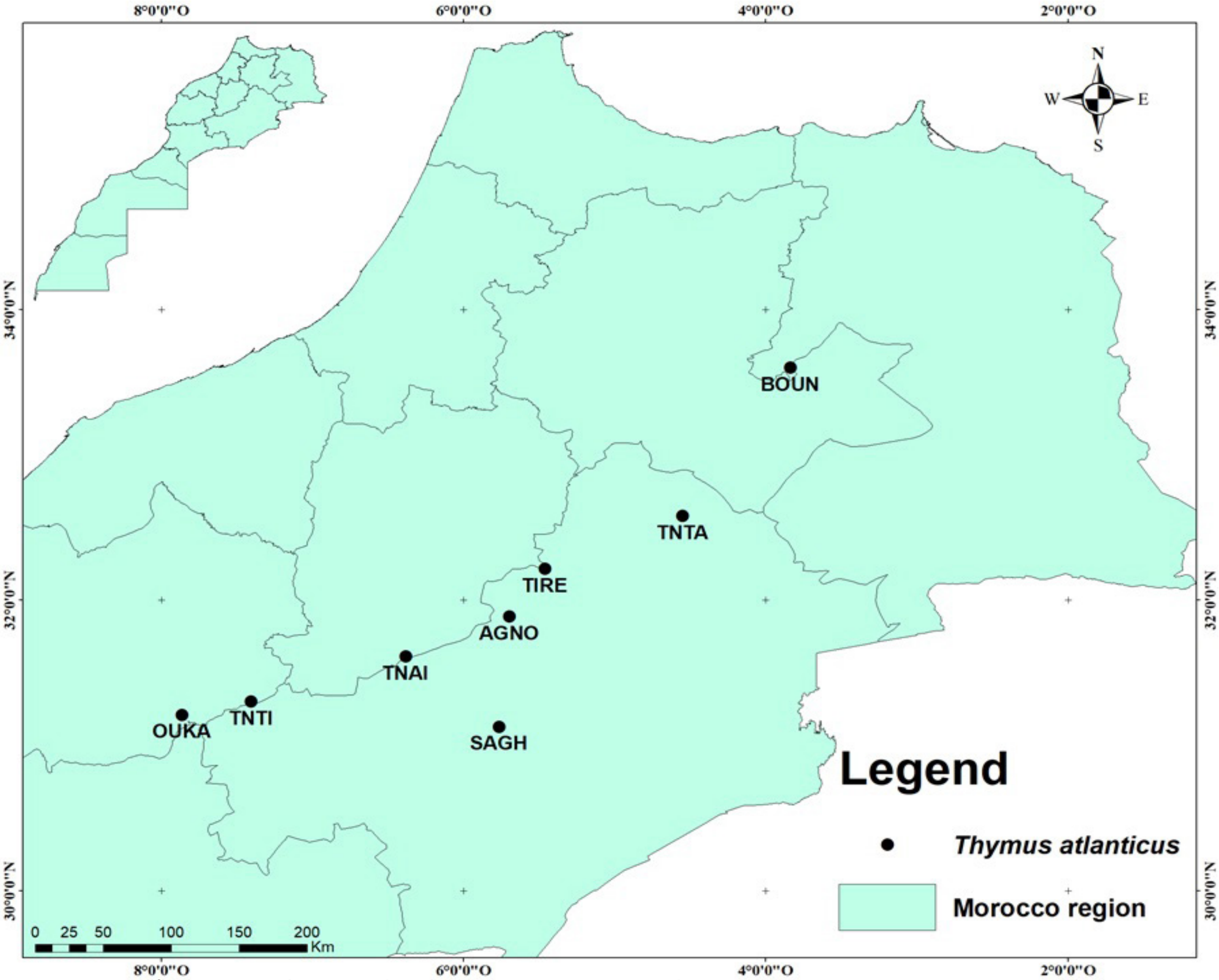

Fig. 1. Map of *Thymus atlanticus* distributions (localities) in the studied regions. TNTI: Tizi n'Tichka; TNAI: Tizi n'Ait Imi; TNTA: Tizi n'Talghemt; BOUN: Bou-Naceur; TIRE: Tireghist; SAGH: Saghro; AGNO: Aghenbo N'Orz; OUKA: Oukaimeden.

Table 1
Geographical and climatic data of eight localities of *T.atlanticus*.

Locality	Region	Longitude	Latitude	Altitude (m)	Precipitation (mm)	Temperature (°C)
Aghenbo N'Orz	High Atlas	31°53'05.2"N	5°41'46.5"W	2895	327.48	11.61
Bou-Naceur	Middle Atlas	33°35'59.1"N	3°50'18.5"W	2551	343.33	15.58
Tireghist	High Atlas	32°12'53.7"N	5°27'44.9"W	2639	327.48	11.61
Oukaimeden	High Atlas	31°12'34.8"N	7°51'44.3"W	2763	304.48	15.34
Saghro	Anti-Atlas	31°07'37.1"N	5°45'55.3"W	2290	107.29	18.78
Tizi n'Tichka	High Atlas	31°18'00.8"N	7°24'23.7"W	2715	244.94	15.79
Tizi n'Ait Imi	High Atlas	31°36'35.9"N	6°22'55.8"W	2865	267.19	12.62
Tizi n'Talghmt	High Atlas	32°34'45.2"N	4°33'10.2"W	2070	370.80	14.64

from thymol and carvacrol, while PC2 indicated negative contributions from all compounds except for α-terpinyl acetate and linalool. Tireghist and Tizi n'Tichka EOs are grouped together, characterized by their high levels of carvacrol. The three localities—Aghanbo N'Orz, Bou-Naceur, and Saghro—are rich in thymol. Moreover, Bou-Naceur and Saghro EOs are noted for their abundance of *o*-cymene and γ-terpinene. However, Oukaimeden EO is distinguished by its high content of nerolidol, while Tizi n'Ait Imi EO was characterized by a significant presence of shyobunol. On the other hand, Tizi n'Talghemt EO is notable for its α-terpinyl acetate and linalool content.

Table 2
Chemical composition of EOs isolated from the eight localities of *Thymus atlanticus*.

RT	RRI	Compound	Region							
			Aghenbo N'Orz	Bou-Nacuer	Tireghist	Oukaimeden	Saghro	Tizi n'Tichka	Tizi n'Ait Imi	Tizi n'Talghemt
7.351	924	β-Thujene	-	0.6	-	-	1.1	-	0.1	0.2
7.63	932	α-Pinene	0.07	0.9	0.04	0.1	1.9	0.2	2.8	2.7
8.318	945	Camphene	0.1	0.3	0.04	0.4	0.4	0.4	3.6	0.9
9.744	974	β-Pinene	-	0.1	-	-	0.7	-	0.7	0.8
9.89	974	1-Octen-3-ol	0.2	0.06	0.2	-	0.08	0.2	-	0.1
10.298	979	3-Octanone	0.1	0.03	0.05	-	-	-	-	-
10.615	988	α-Myrcene	-	0.6	-	-	-	-	2.4	0.8
10.84	988	3-Octanol	0.2	0.03	0.3	0.1	-	0.2	-	-
11.361	1002	α-Phellandrene	-	0.2	-	-	0.2	-	-	-
11.745	1008	3-Carene	-	0.05	-	-	0.07	-	-	-
12.162	1086	α-Terpinene	0.1	1.6	0.03	-	2.2	0.1	0.1	-
12.674	1022	***o*-Cymene**	1.6	**12.5**	0.4	0.1	**15.9**	1.1	1.0	0.8
12.983	1024	Limonene	0.1	0.3	0.04	0.1	0.4	0.1	3.8	-
13.116	1026	Eucalyptol	1.7	0.5	0.6	0.2	0.02	0.1	0.4	0.7
14.534	1044	α-Ocimene	0.1	0.3	-	0.1	0.05	-	0.8	0.7
15.255	1054	**γ-Terpinene**	0.8	**13.9**	0.4	0.1	**19.4**	0.9	1.0	0.2
15.834	1098	cis-4-Thujanol	0.2	0.9	0.5	0.5	0.6	1.1	0.6	1.2
16.168	1088	Linalool oxide	-	-	-	-	-	-	-	0.9
17.127	1097	2-Tonanol	0.1	0.03	0.07	-	0.02	0.1	-	-
18.448	1130	1-Terpineol	0.2	0.3	0.1	0.2	0.3	0.5	0.3	-
18.849	1131	Dihydrolinalool	3.2	0.7	4.05	3.7	2.4	3.2	0.8	0.9
19.232	1098	**Linalool**	-	-	-	-	-	-	-	**28.2**
19.311	1108	3,5,5-Trimethyl-1-cyclohexene	-	-	-	-	-	-	-	0.2
20.091	1110	1-Octen-3-yl-acetate	-	-	-	-	-	-	-	1.05
20.441	1070	*trans*-4-Thujanol	-	-	-	-	-	-	-	0.2
21.917	1183	Isopinocarveol	-	-	-	-	-	-	-	0.1
22.563	1141	Camphor	**8.2**	0.1	2.8	8.2	-	7.0	0.4	2.6
22.805	1144	*cis*-Verbenol	0.1	-	-	0.3	0.2	0.2	0.2	0.5
24.856	1165	Borneol	2.0	1.4	0.8	1.6	1.6	6.0	0.6	1.3
26.098	1177	Terpinen-4-ol	-	-	-	-	-	-	-	2.1

Table 2
Continued.

RT	RRI	Compound	Region							
			Aghenbo N'Orz	Bou-Nacuer	Tireghist	Oukaimeden	Saghro	Tizi n'Tichka	Tizi n'Ait Imi	Tizi n'Talghemt
27.199	1166	Nonenol	-	-	0.3	0.09	-	0.1	-	-
27.249	1179	Cymen-8-ol	-	0.1	-	-	0.04	-	-	0.2
27.707	1186	α-Terpineol	2.0	1.0	1.0	2.2	1.0	2.4	0.5	3.1
28.145	1191	Dihydrocarvone	0.3	0.05	0.2	0.2	0.04	0.7	0.8	0.1
30.676	1227	Nerol	-	-	0.7	0.25	-	-	-	-
32.226	1257	Linalyl acetate	-	-	-	-	-	-	-	0.5
31.201	1232	**Thymol methyl ether**	**19.0**	0.9	0.3	2.3	0.8	2.2	0.2	-
31.597	1241	Carvacrol methyl ether	0.4	-	-	0.07	0.02	3.6	-	-
32.364	1235	Neral	-	-	0.3	0.3	-	0.4	-	-
32.397	1264	**Geraniol**	3.3	0.8	**338**	**11.6**	-	2.6	-	-
33.16	1264	Geranial	0.1	-	0.5	0.4	-	0.1	-	-
33.652	1284	Bornylacetate	1.0	-	0.5	1.8	-	1.4	0.4	1.8
34.178	1289	**Thymol**	**29.9**	**22.4**	**6.6**	0.2	**13.1**	5.2	3.0	-
34.365	1289	***ρ-Cymen-7-ol***	-	-	-	-	**16.0**	-	-	-
34.636	1298	**Carvacrol**	2.7	**31.7**	**23.3**	0.07	**9.8**	**28.7**	**5.5**	-
28.824	1189	α-Thujenal	-	-	-	-	-	-	-	0.2
36.466	1334	**α-Terpinyl acetate**	-	-	-	-	-	-	-	**28.7**
36.512	1349	Thymol acetate	-	0.2	-	-	-	-	-	-
29.787	1219	*trans*-carveol	-	-	-	-	-	-	-	0.2
36.921	1359	Neryl acetate	-	-	-	0.5	-	0.1	-	0.2
37.154	1370	Carvacryl acetate	-	0.4	-	-	-	0.1	-	-
37.225	1374	α-Copaene	-	-	-	-	-	-	0.4	0.7
37.241	1387	β-Cubebene	-	-	-	-	0.1	-	-	0.2
37.529	1387	β-Bourbonene	-	-	-	-	-	-	0.2	-
37.596	1363	Geranyl acetate	0.3	-	**5.2**	**8.8**	-	-	2.2	-
37.808	1389	β-Elemene	-	-	-	-	-	-	0.2	0.1
38.342	1405	1,3,5-Trimethoxy benzene	-	0.1	-	-	-	-	-	-

Table 2
Continued.

RT	RRI	Compound	Region							
			Aghenbo N'Orz	Bou-Nacuer	Tireghist	Oukaimeden	Saghro	Tizi n'Tichka	Tizi n'Ait Imi	Tizi n'Talghemt
38.709	1408	Caryophyllene	**8.9**	2.6	**6.0**	2.0	2.7	1.8	6.1	0.5
39.026	1113	*trans*-*p*-Mentha-2,8-dienol	-	-	-	-	-	-	-	0.2
39.755	1452	Humulene	0.4	0.1	0.3	0.2	0.1	0.2	0.4	-
39.985	1439	Aromadendrene	-	0.07	0.04	0.2	-	0.2	1.1	0.2
40.581	1484	Germacrene D	0.3	-	0.4	0.6	-	0.4	1.2	0.4
40.939	1490	3-(1,1-dimethylethyl)-4-methoxy-Phenol,	0.1	-	-	-	-	-	-	-
41.035	1492	γ-Elemene	-	-	-	-	-	0.3	2.5	0.2
41.373	1505	β-Bisabolene	0.07	0.4	2.7	0.2	-	2.2	3.3	0.1
41.527	1500	γ-Muurolene	0.3	0.1	0.1	-	0.06	0.1	0.7	0.7
41.773	1522	δ-Cadinene	0.2	0.2	0.3	0.5	0.2	0.6	0.7	0.3
42.695	1423	Z-8-Hydroxy-linalool	-	-	0.5	-	-	-	-	-
42.377	1671	Hedycariol	-	-	-	-	-	-	-	0.1
42.936	1532	**Nerolidol**	-	-	-	**37.0**	-	**9.7**	-	0.8
43.178	1535	10-*epi*-Cubebol	0.1	0.07	0.5	-	0.03	1.8	3.7	0.15
43.157	1572	(-)-Spathulenol	-	-	-	-	-	-	-	0.4
43.378	1582	Caryophyllene oxide	3.1	1.1	1.7	1.2	1.1	0.8	2.7	0.8
43.649	1592	Viridiflorol	-	-	-	0.1	-	-	-	-
43.779	1601	Geranyl2-methylbutyrate	-	-	0.3	-	-	-	-	-
43.878	1602	Ledol	-	-	-	-	-	-	0.4	-
44.033	1608	Humulene epoxide II	0.1	-	0.06	-	0.02	0.8	0.4	-
44.049	1639	Isoaromadendrene epoxide	-	-	-	0.2	-	-	-	-
44.174	1645	Cubenol	0.1	-	-	-	-	-	0.4	0.4
44.578	1630	γ-Eudesmol	-	-	-	-	-	-	0.1	-
44.8	1640	Tau-Cadinol	1.1	0.2	0.1	0.6	0.08	0.5	3.7	2.4
45.033	1649	β-Eudesmol	0.1	0.03	-	-	-	-	-	-
45.116	1652	α-Cadinol	0.1	0.05	0.2	1.3	0.06	1.0	1.7	0.4
45.625	1624	(*E*)-Farnesene epoxide	0.2	-	-	-	-	-	-	-

Table 2
Continued.

RT	RRI	Compound	Region							
			Aghenbo N'Orz	Bou-Nacuer	Tireghist	Oukaimeden	Saghro	Tizi n'Tichka	Tizi n'Ait Imi	Tizi n'Talghemt
45.796	1688	**Shyobunol**	-	-	-	0.2	-	0.2	**26.3**	0.7
45.817	1689	*cis*-Jasmone	-	-	-	-	-	-	-	0.1
45.862	1690	Z-α-*trans*-Bergamotol	-	-	-	-	-	-	0.3	-
45.913	1692	Caparratriene	-	-	-	-	-	-	0.2	-
Monoterpene hydrocarbons			3.0	31.3	0.9	0.9	42.3	2.9	16.3	7.2
Oxygenated monoterpenes			75.5	61.8	82.7	43.7	46.0	66.2	15.8	74.9
Sesquiterpene hydrocarbons			10.1	3.5	9.9	3.6	3.2	5.8	16.9	2.9
Oxygenated sesquiterpenes			4.9	1.4	2.9	40.6	1.3	14.7	39.7	6.9
Total			93.5	97.9	96.3	88.7	92.8	89.6	88.8	92.1
EO yield(%)			0.54%	1.02%	0.65%	0.57%	3.82%	0.57%	0.82%	1.67%

Table 3
Major EO chemical compounds of *Thymus atlanticus*.

Compound	RT	RRI	Region							
			Aghnbo N'Orz	Bou-Nacuer	Tireghist	Oukaimeden	Saghro	Tizi n'Tichka	Tizi n'Ait Imi	Tizi n'Talghemt
o-Cymene	12.674	1022	1.6	12.5	0.3	0.08	15.9	1.1	1.0	0.8
γ-Terpinene	15.255	1054	0.8	13.9	0.4	1.0	19.4	0.9	1.0	0.2
Linalool	19.232	1098	-	-	-	-	-	-	-	28.2
Thymol methyl ether	31.201	1232	19.0	0.9	0.3	2.3	0.8	2.2	0.2	-
α-terpinyl acetate	36.466	1334	-	-	-	-	-	-	-	28.7
Geraniol	32.397	1264	3.3	0.8	33.8	11.6	-	2.6	-	-
Thymol	34.178	1289	29.9	22.4	6.6	0.2	13.1	5.2	3.0	-
p-Cymen-7-ol	34.365	1289	-	-	-	-	16.0	-	-	-
Carvacrol	34.636	1298	2.7	31.7	23.3	0.07	9.8	28.7	5.5	-
Nerolidol	42.936	1532	-	-	-	37.0	-	9.7	-	0.8
Shyobunol	45.796	1688	-	-	-	0.2	-	0.2	26.3	0.7

Table 4
Correlation between major compounds in Eos of *T. atlanticus* and environmental parameters.

	o-Cymene	γ-Terpinene	Linalool	Thymol methyl ether	α-Terpinyl acetate	Geraniol	Thymol	p-Cymen-7-ol	Carvacrol	Nerolidol	Shyobunol	Altitude(m)	Precipitation (mm)	Temperature(°C)
o-Cymene	1													
γ-Terpinene	0.997	1												
Linalool	-0.215	-0.235	1											
Thymol methyl ether	-0.175	-0.212	-0.201	1										
α-Terpinyl acetate	-0.215	-0.235	1	-0.201	1									
Geraniol	-0.364	-0.332	-0.225	-0.116	-0.225	1								
Thymol	0.442	0.396	-0.370	0.718	-0.370	-0.186	1							
p-Cymen-7-ol	0.755	0.789	-0.142	-0.153	-0.142	-0.225	0.112	1						
Carvacrol	0.306	0.295	-0.390	-0.281	-0.390	0.217	0.214	-0.090	1					
Nerolidol	-0.322	-0.296	-0.159	-0.079	-0.159	0.136	-0.420	-0.184	-0.270	1				
Shyobunol	-0.215	-0.201	-0.118	-0.194	-0.118	-0.232	-0.275	-0.149	-0.233	-0.182	1			
Altitude(m)	-0.398	-0.399	-0.743	0.468	-0.743	0.192	0.247	-0.433	0.077	0.259	0.358	1		
Precipitation (mm)	-0.564	-0.609	0.409	0.172	0.409	0.244	0.022	-0.872	-0.024	0.0430	-0.084	0.088	1	
Temperature (°C)	0.703	0.721	0.023	-0.425	0.023	-0.464	-0.125	0.705	0.124	0.196	-0.307	-0.533	-0.654	1

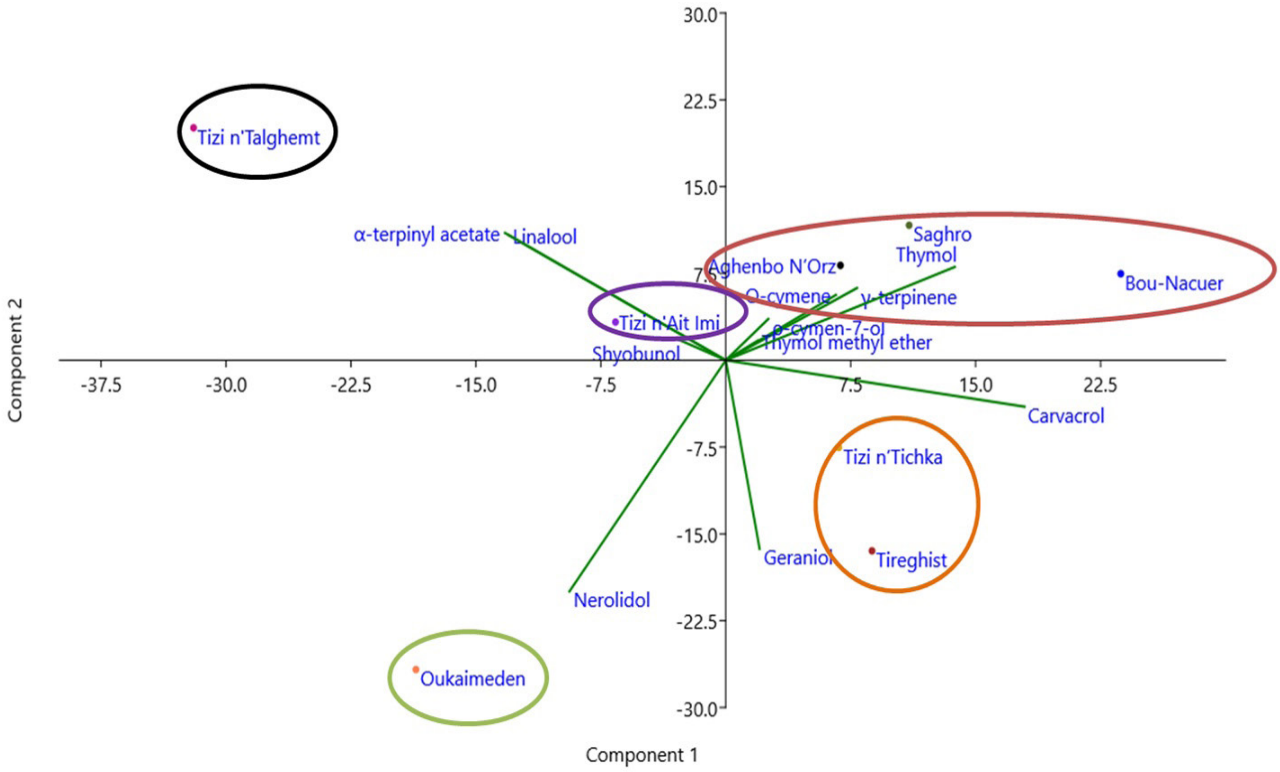

Fig. 2. Scatter plot based on the first two principal components of EO main compounds of *T. atlanticus* in the eight localities.

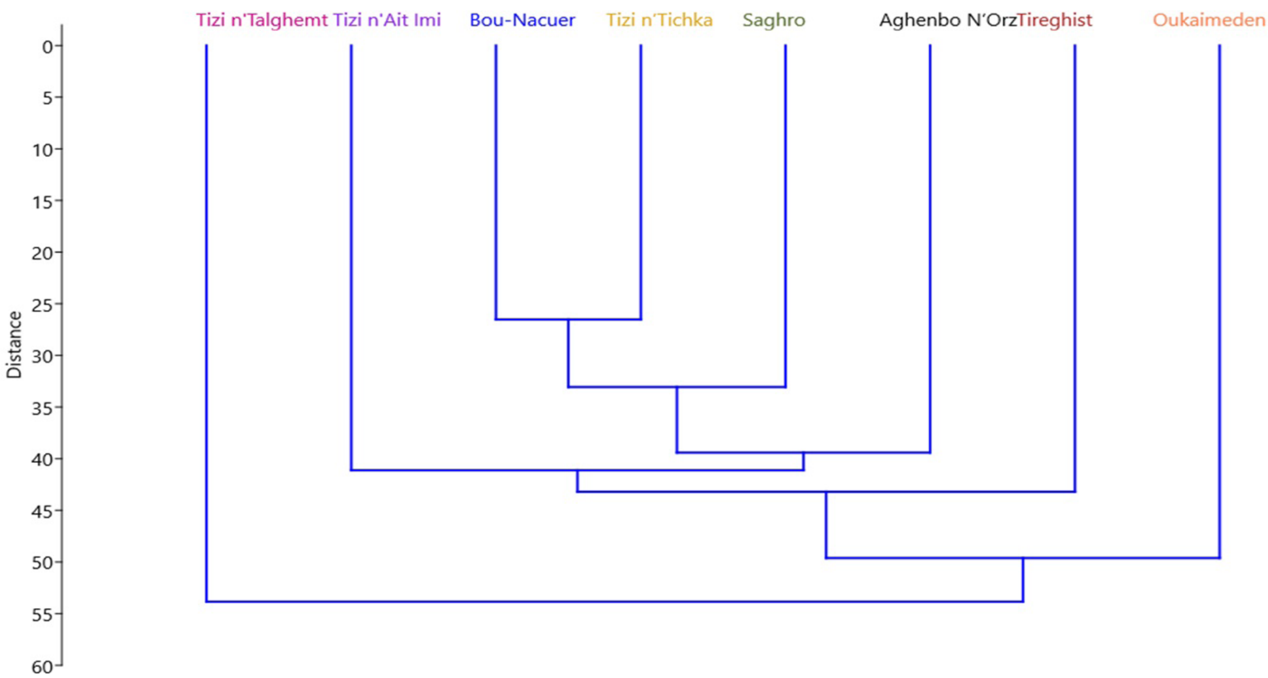

Fig. 3. Dendrogram obtained by cluster analysis based on the chemical compositions dissimilarity relationships of eight Eos samples of *T. atlanticus*.

3.4. Cluster analysis

Cluster analysis facilitated the classification of populations into six main groups based on the content of the main compounds; *o*-Cymene, γ-terpinene, thymol methyl ether, thymol, *p*-cymen-7-ol, carvacrol, geraniol, nerolidol, shyobunol, α-terpinyl acetate, and linalool. The first, second, third, fourth, and fifth groups each comprised a single population for each group; Tizi n'Talghemt, Oukaimeden, Tireghist, Tizi n'Ait Imi, and Aghnbo N'Orz, respectively. However, the sixth group included three localities: Saghro, Bou-Naceur, and Tizi n'Tichka (Fig. 3).

The chemical composition of *Thymus atlanticus* varies from localities to localities. Nine majority compounds were identified: *o*-Cymene, γ-terpinene, thymol methyl ether, geraniol, thymol, *p*-cymene-7-ol, carvacrol, nerolidol, α-terpinyl acetate, linalool, and shyobunol. Similarly, Mohamed et al., (2021) showed that the EO of *T. atlanticus* is characterized by carvacrol (47.1%), *p*-cymene (7.5%). Moreover, Elbouny et al. (2022) reported that the main components of *Thymus atlanticus* were thymol(23.7%) and carvacrol(22.8%), followed by γ-terpinene (20.7%) and *p*-cymene(18.5%). Also, the major components of *T. atlanticus* were carvacrol (21.6%) and borneol (21.1%) ,followed by γ-terpinene (10.0%), *o*-cymene (8.1%) and camphene (7.3%) (Nafis et al., 2021). Thus, *T.serpyllum* from Morocco (synonymous with *T. atlanticus*), was characterized by a particular composition essentially dominated by linalyl acetate (52.2%) and *(E)*-nerolidol(15.1%) (Jamali et al., 2012). The main compounds *o*-cymene, γ-terpinene and *p*-cymen-7-ol show a negative correlation with precipitation. However, they are positively correlated with temperature. Linalool and α-terpinyl acetate are positively correlated with altitude. Which means that the effect of the environment on the chemical composition remains small. Salgueiro et al., (1997) remarked that different EO chemotypes can be found in the same habitats, suggesting that the environmental effects are only partially responsible for different chemical compositions. In contrast ,Sáezand Stahl-Biskup, (2002) demonstrated that chemical polymorphism in *Thymus* populations was closely related to the high variability of ecological conditions. El Hadj Ali et al. (2010) showed that in *T. algeriensis* the distribution of EO chemotypes was not always consistent with the bioclimatic zones and seemed rather linked to the geographical location and local selective force acting on the diversity of chemotypes. Very often, the initial hypothesis regarding the variation in the composition of EOs from different species within the genus *Thymus* is linked to hybridization processes and introgression between different species or chemotypes (Sáez,1995). In addition, the EO profile of *T. daenensis,* changes in accordance with its phenological cycle (Rustaiee et al., 2010; Rustaiee et al. , 2011). Genetic variability also influences the chemical composition of Eos (Zarshenas and Krenn, 2015). In fact, local abiotic factors such as topography, moisture, temperature, and edaphic conditions and/or biotic factors including associated fauna and flora influence the terpene biosynthesis pathways and contribute to the development of distinct chemical profiles (Croteau and Gershenzon, 1994).

4. Concluding remarks

The GC-MS analysis of eight localities of *T. atlanticus* identified nine main compounds, namely *o*-cymene, γ-terpinene, thymol methyl ether, geraniol, thymol, *p*-cymene-7-ol, carvacrol, nerolidol, linalool, α-terpinyl and shyobunol. Furthermore, *T. atlanticus* exhibited significant chemical polymorphism. In addition, the majority of the main compounds showed no correlation with environmental parameters. These findings provide valuable profile information that can be utilized to initiate the domestication of *T. atlanticus*.

Author contribution statement

BO: Investigation, resources, formal analysis, and writing-original draft. HE and NL: Investigation and software. KS and AHB: Visualization and methodology. GD: Visualization and editing the original draft. AB and CA: Methodology, Supervision, and Validation.

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Conflict of interest

The authors declare that there is no conflict of interest.

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