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Essential Oil as a Source of Bioactive Constituents for the Control of Insect Pests of Economic Importance in Tunisia

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Abstract

Essential oils from medicinal and aromatic plants are known as a source of secondary metabolites. They act as antimicrobial, antispasmodic, antiviral and anti-insect agents. In addition, essential oils of several species have been recently qualified as replacement alternatives to synthetic pesticides. Tunisia is located in the Mediterranean basin area, a temperate zone characterized by the greatest diversity on the planet since we find around 25,000 species and a very high percentage of these are endemic. The present mini-review comprises an investigation on major and predominant bioactive components and insecticidal potential of various species of *Eucalyptus* and *Artemisia* grown in Tunisia.

The aim of this mini-review is to bring together most of the available scientific research in Tunisia conducted on insecticidal potential of the genera *Eucalyptus* and *Artemisia*, which is currently documented across various publications. Through this mini-review, I hope to attract the attention on the most bioactive essential oils as a source of bioactive constituents.

This review has been compiled using references from major work on essential oil and their bioactive components against Tunisian strains of major stored product insect pests.

Results revealed that the different species either from *Eucalyptus* or *Artemisia* genera have a vast range of insecticidal activities including fumigant, contact and repellent effects. Some very important components have been discovered from these genera, notably 1,8 cineole, and α-pinene from *Eucalyptus* and β-thujone and Camphor from *Artemisia*.

Various species of *Eucalyptus* and *Artemisia* seems to hold great potential for in-depth investigation for various insecticidal activities, especially their effects on the stored product insect pests.

Keywords: *Eucalyptus; Artemisia*; Stored product; Pest; Tunisia

Introduction: Context and Objectives

The development of pest management and control is striving toward a future of sustainable agriculture. Insect pests caused serious problems in agricultural ecosystems during cropping or after harvest. Pesticides have been a major contributor to the increase of agricultural productivity and food supply. Nevertheless, they are a source of concern because of human and environmental health side effects [1]. The undesirable side effects include: target pest resistance and/or resurgence, secondary pest outbreaks, food residue problems, environmental pollution, human toxicity and ecotoxicological risks. Consequently, growing concern about environmental protection, human health, and food safety has brought renewed interest in pesticide use in agriculture. The search for solutions to these problems led to the search and development of more effective alternatives, friendly to environment and respectful to human health. Subsequently, researches has been concentrated on plants for solutions leading to the production of a multitude of secondary compounds that can have toxic, growth reducing, and antifeedant properties against insects [2]. The use of plant extracts (botanical insecticides) to protect crops and stored products is as old as crop protection. Indeed, prior to the development and commercial success of synthetic insecticides beginning in the 1940s, botanical insecticides were major weapons in the farmer's arsenal against crop pests [3]. Four major types of botanical insecticides are being used for insect control including pyrethrum, rotenone, neem, and essential oils [4].

Aromatic plants and their essential oils have been used since antiquity in flavor and fragrances, as spice, in medicines, as antimicrobial/insecticidal agents, and to repel insect or protect stored products [5-7]. Presence of volatile monoterpenes or essential oils in the plants provides an important defense strategy to the plants, particularly against herbivorous insect pests and pathogenic fungi [8]. These constitute effective alternatives to synthetic pesticides without producing adverse effects on the environment [5,9].

The interest in essential oils has regained momentum during the last decade, primarily due to their fumigant and contact insecticidal activities and the less stringent regulatory approval mechanisms for their exploration due to long history of use [4].

Several studies suggest that essential oils may help fend off insect pests [7,10-13]. In fact, essential oils may provide protection comparable to several widely used synthetic insecticides. Furthermore, essential oils from various plant species show important biological effects that include: cytotoxicity [14], phototoxicity [15], nuclear mutagenicity [16,17], cytoplasmic mutagenicity [18], carcinogenicity [19] and antimutagenic properties [20-22].

This mini-review presents researches conduced in Tunisia for assessing insecticidal effects of some essential oils extracted from

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various aromatic and medicinal plants. It also provides an overview of their chemical composition and their main bioactive components. This mini-review covers major research that analyzes essential oils as alternative approach to address issues of chemicals use replacement, as well as potential considerations of effective control using essential oils. The mini-review summarizes existing and ongoing research works on the valorization of essential oils against insect pests in Tunisia. Analysis is provided to relate essential oils applications to the larger context of Integrated Pest Management (IPM) strategies. This mini-review will recapitulate all essential oils achievement in terms of insect pests control; it will mainly focus on stored product pests.

This mini-review will focus on essential oils extracted from different Artemisia and Eucalyptus species. The choice was made on the base that the genus Artemisia is native to temperate and Northern Africa regions including Tunisia while Eucalyptus, Australian native genus, was introduced and well adapted in Tunisia. The *white wormwood Artemisia herba-alba* Asso. The absinthe wormwood *Artemisia absinthium* L. are native to northern Africa. They are common species widely distributed in the Mediterranean basin and in Tunisia. These species are valued because they are used in folk medicine, as spices and as flavoring agents. Moreover, Eucalyptus is Australian native genus that had been introduced and adapted in Tunisia since 1957. It had been used as fire wood, for the production of mine wood and against erosion. Furthermore, in this mini-review, insecticidal proprieties of essential oils were assessed against beetles and moths species of economic importance causing quantitative and qualitative losses to various stored products including dates, cereal products and various others food stuffs. On the other hand, the dried-fruit beetle, *Carpophilus hemipterus L., the* sawtoothed grain beetle *Oryzaephilus surinamensis* L., the red flour beetle *Tribolium castaneum Herbst.,* the tropical warehouse *moth Ephestia cautella* Walker, the Mediterranean flour *moth Ephestia kuehniella Zeller, the carob moth Ectomyelois ceratoniae Zeller and* the Indian meal *moth Plodia interpunctella* (Hübner) are causing significant economic losses during storage in Tunisia. These insects are reported as major pests of stored commodities in Tunisia. These devastating insects cause loss of weight and downgrading of the commercial value of the products.

Bioactive essential oils from Eucalyptus species

This section highlights the chemical composition of essential oils as a source of variation of anti-insect properties. The main investigated oils were those from the genus *Eucalyptus.*

Table 1 reported chemical composition of respectively 10 Eucalyptus species namely: *E. astringens, E. leucoxylon*, *E. lehmani,*

N°	Components	RI	KI	*E. astringens*	E. leucoxylon	*E. lehmani*	***E. rudis***	***E. camaldulensis***	***E. dumosa***	***E. transcontinentalis***	***E. cinerea***	***E.maidenii***	*E. viminalis*
1	**α-thujene**	8.23	879	tr	tr	tr	tr	tr	tr	0.14	tr	tr	tr
2	**α-pinene**	9.25	944	**29.83**	**32.73**	**31.61**	**14.49**	**16.49**	**2.93**	**7.96**	**8.13**	**4.54**	**1.65**
3	Phellandrene	10.71	995	tr	tr	tr	tr	tr	tr	**0.47**	0.24	tr	tr
4	β-pinene	10.82	1002	**0.43**	tr	tr	**3.91**	tr	tr	0.17	tr	tr	tr
5	β-myrcene	10.83	1003	tr	tr	tr	tr	tr	tr	tr	tr	tr	0.37
6	Sabinene	11.17	1010	0.03	tr	tr	tr	tr	tr	tr	tr	tr	tr
7	Cymene	12.18	1033	tr	tr	tr	tr	tr	**0.93**	**1.83**	tr	tr	tr
8	**1,8-cinéole**	12.3	1035	**17.29**	**17.62**	**34.56**	**19.87**	**20.62**	**79.44**	**82.82**	**67.22**	**75.64**	**75.79**
9	isopentyl isopentanoate	13.77	1050	tr	tr	tr	tr	tr	0.11	tr	tr	tr	tr
10	Endo-Fenchol	14.05	1065	tr	tr	tr	tr	tr	0.24	tr	tr	tr	tr
11	Cis-Ocimene	14.15	1075	tr	tr	tr	tr	tr	tr	tr	**0.6**	tr	**1.17**
12	**Trans-linalool oxide**	14.17	1077	tr	tr	tr	tr	0.26	tr	tr	tr	tr	tr
13	γ-terpinene	14.26	1079	**0.64**	**0.97**	**1.79**	**6.04**	**4.8**	tr	tr	0.27	tr	tr
14	Cis-sabinene hydrate	14.36	1081	tr	tr	tr	tr	0.19	tr	tr	tr	tr	tr
15	α-terpinolene	14.58	1086	0.17	0.16	0.32	0.34	tr	tr	tr	**13.95**	tr	**0.6**
16	Linalool	14.71	1089	0.05	0.06	0.07	0.1	**1.46**	tr	tr	tr	tr	tr
17	Dehydro-p-cymene	14.74	1090	tr	tr	tr	tr	**1.23**	tr	tr	**0.68**	**0.63**	tr
18	Isoamyl isovalerate	14.8	1091	tr	0.21	tr	tr	tr	tr	tr	tr	**0.4**	**0.65**
19	Butanoic acid	15.04	1096	tr	tr	0.12	0.04	tr	tr	tr	tr	tr	tr
20	D-frenchyl alcohol Fenchol	15.08	1097	0.07	0.23	0.9	tr	tr	tr	tr	tr	tr	tr
21	β-Thujone	15.17	1099	tr	tr	tr	tr	**0.54**	tr	tr	tr	tr	tr
22	Octa-2,4,6-triene	15.27	1104	tr	tr	tr	0.07	tr	tr	tr	tr	tr	tr
23	Cis-Geraniol	15.36	1107	tr	tr	tr	tr	**0.75**	tr	tr	0.18	tr	tr
24	3-Methylene cycloheptane	15.41	1112	tr	tr	tr	tr	**0.44**	tr	tr	tr	tr	tr
25	α-campholene aldehyde	15,6	1123	tr	0.14	0.16	tr	tr	tr	tr	tr	tr	tr
26	exo-methyl-camphenilol	16,04	1149	0.05	0.08	tr	tr	tr	tr	tr	tr	tr	tr
27	**Trans-pinocarveol**	16,13	1155	**3.39**	**2.96**	**2.31**	0.31	tr	**9.46**	**3.68**	tr	**2.71**	**0.42**
28	**Pinocarvone**	16,76	1192	**2.23**	**0.82**	**0.56**	0.08	tr	tr	tr	tr	tr	tr
29	Borneol	16,91	1207	**0.84**	0.19	1.6	tr	tr	0.39	tr	tr	tr	tr
30	Terpinene-4-ol	17,1	1213	**1.44**	**1.45**	**1.15**	**4.46**	**4.45**	tr	tr	**0.78**	0.33	**0.74**
31	Cyclohexanol	17.20	1224	tr	tr	tr	tr	tr	tr	tr	tr	**0.96**	**1.45**
32	Sabinol	17,44	1225	0.08	tr	tr	tr	tr	tr	tr	tr	tr	tr
33	Linalyl propionate	17.49	1226	tr	**6.32**	tr	tr	tr	tr	tr	tr	tr	tr

34	**α-terpineol**	17,55	1229	**5.11**	tr	**6.82**	**4.32**	**0.79**	0.25	tr	tr	**3.25**	**1.25**
35	Myrtenol	17,65	1233	0.15	tr	tr	tr	tr	0.17	tr	tr	tr	tr
36	**β-fenchyl alcohol**	17,74	1236	tr	tr	tr	tr	tr	tr	tr	**4.68**	tr	**0.46**
37	Trans-carveol	18,08	1247	0.16	0.13	0.1	0.07	tr	tr	tr	tr	tr	tr
38	Trans-Piperitol	18.24	1248	tr	tr	tr	tr	**0.49**	tr	tr	tr	tr	Tr
39	Cuminic aldehyde	18.38	1249	tr	tr	tr	0.1	**3.47**	tr	tr	tr	tr	tr
40	Carvone	18,64	1267	0.06	0.03	tr	tr	tr	tr	tr	tr	tr	tr
41	Geraniol	18,79	1272	0.27	**0.63**	0.29	0.34	tr	tr	tr	tr	tr	tr
42	Piperitone	18.96	1278	tr	tr	tr	tr	**1.45**	tr	tr	tr	tr	tr
43	Z-citral	19.16	1284	tr	0.06	0.07	tr	tr	tr	tr	tr	tr	tr
44	E-citral	19.21	1285	tr	tr	0.04	tr	tr	tr	tr	tr	tr	tr
45	Phellandral	19.38	1292	tr	0.08	tr	0.07	tr	tr	tr	tr	tr	tr
46	Borneol acetate	19.55	1295	tr	tr	0.04	0.04	Tr	tr	tr	tr	tr	tr
47	Thymol	19,69	1303	tr	tr	0.06	0.02	tr	tr	tr	tr	tr	tr
48	Isothymol	20,07	1318	0.16	0.29	0.09	0.13	**7.3**	tr	tr	tr	tr	tr
49	Ethyl mesylate	20.13	1320	tr	tr	tr	tr	**4.27**	tr	tr	tr	tr	tr
50	Cuminyl alcohol	20.44	1332	tr	tr	tr	tr	**3.33**	tr	tr	tr	tr	tr
51	Methyl geranate	20.64	1338	tr	**1.7**	tr	tr	tr	tr	tr	**1.28**	tr	tr
52	Bicycloelemene	20,88	1349	**0.46**	tr	tr	0.18	tr	tr	tr	tr	tr	tr
53	Camphene	21,29	1364	tr	tr	**8.72**	0.04	tr	tr	tr	tr	tr	tr
54	α-terpinene	21.66	1379	tr	tr	tr	tr	**0.65**	tr	tr	tr	tr	tr
55	Isoledene	21,79	1384	0,06	0.04	tr	0.1	tr	tr	tr	tr	tr	tr
56	α-copaene	22.11	1397	Tr	Tr	tr	tr	0.1	tr	tr	tr	tr	tr
57	Geranyl acetate	22.18	1399	tr	tr	0.1	**0.44**	tr	tr	tr	tr	tr	tr
58	β-elemene	22,22	1401	0.05	tr	tr	tr	tr	tr	tr	tr	tr	tr
59	α-gurjunene	22,76	1421	tr	**0.49**	0.05	**0.57**	tr	tr	tr	tr	tr	0.34
60	**Bicyclogermacrene**	23,06	1433	**3**	tr	0.28	**2.85**	tr	tr	tr	0.16	tr	tr
61	Trans-caryophyllene	23,08	1434	**1.24**	tr	0.15	tr	**0.87**	tr	tr	tr	tr	tr
62	β-caryophyllene	23,1	1435	tr	tr	tr	**0.67**	tr	tr	tr	tr	tr	tr
63	Docosane	23.15	1436	tr	tr	tr	tr	tr	tr	tr	tr	0.34	tr
64	β-gurjunene	23,35	1444	0.09	0.11	tr	tr	0.09	tr	tr	tr	tr	tr
65	Geranyl acetone	23.71	1457	tr	0.05	tr	tr	tr	tr	tr	tr	tr	tr
66	**Aromadendrene**	23,73	1459	**5.01**	**3.61**	**1.02**	**6.37**	**3.93**	tr	0.23	tr	**3.25**	**1.65**
67	γ-gurjunene	23,82	1462	**1.27**	tr	tr	tr	tr	tr	tr	tr	**2.82**	**7.6**
68	α-caryophyllene	23,93	1466	0.1	tr	tr	tr	tr	tr	tr	tr	tr	tr
69	Naphthalene,1,2,3,4-tetrahydro-6,7-dimethl	24.47	1488	tr	0.1	tr	tr	tr	tr	tr	tr	tr	tr
70	Germacrene-D	24.6	1492	tr	tr	tr	0.04	tr	tr	tr	tr	tr	tr
71	β-eudesmene	24.9	1504	tr	**0.6**	tr	tr	tr	tr	tr	tr	tr	tr
72	1,4-Dimethyltertraline	24.94	1506	tr	tr	tr	tr	**2.03**	tr	tr	tr	tr	tr
73	**γ-gurjunene**	25.2	1518	tr	0.03	0.65	tr	tr	tr	tr	tr	tr	tr
74	Caryophyllene oxide	25.31	1520	tr	tr	tr	tr	0.04	tr	tr	tr	tr	tr
75	α-amorphene	25,32	1521	0.05	tr	tr	tr	tr	tr	tr	tr	tr	tr
76	γ-cadinene	25.41	1526	tr	tr	tr	0.06	tr	tr	tr	tr	tr	tr
77	Epiglobulol	26,52	1575	**1.39**	tr	0.28	tr	tr	tr	tr	tr	**1.03**	**2.83**
78	α-selinene	26.61	1579	tr	tr	0.17	tr	0.09	tr	tr	tr	tr	tr
80	**Viridiflorol**	26,94	1593	**11.24**	**5.27**	tr	**2.06**	**1.36**	tr	tr	tr	tr	tr
81	γ-cadinene	26.96	1594	tr	**0.72**	tr	tr	tr	tr	tr	tr	tr	tr
82	γ-gurjunene	27.33	1610	tr	tr	tr	tr	tr	tr	tr	0.42	tr	tr
83	**Globulol**	27,51	1618	**3.84**	**14.38**	**1.48**	tr	tr	tr	**0.89**	tr	tr	tr
84	Ledene	27,67	1624	tr	0.31	**2.52**	tr	tr	tr	tr	tr	tr	0.36
85	Allospathulenol	27,84	1632	0.2	tr	0.06	tr	tr	tr	tr	tr	tr	tr
86	β-eudesmol	27.9	1635	tr	tr	**0.41**	tr	tr	tr	tr	tr	tr	**0.71**
87	2-Naphthalènemethanol	28.11	1640	tr	tr	tr	tr	tr	0.14	tr	tr	tr	tr
88	Spathulenol	28.16	1646	tr	tr	tr	0.04	**2.36**	tr	tr	0.3	tr	**0.65**
89	β-selinene	28.37	1656	tr	**0.81**	tr	tr	tr	tr	tr	tr	tr	tr
90	Isospathulenol	28,42	1657	**0.97**	tr	0.23	tr	**1.74**	tr	tr	tr	tr	tr
91	γ-selinene	28.48	1660	tr	tr	tr	tr	tr	tr	tr	tr	tr	**0.58**

92	1-Amino-4-bromonaphalene	28,53	1662	0.05	tr	tr	tr	tr	tr	tr	tr	tr	tr
93	t-muurolol	28,56	1664	tr	**0.26**	**0.17**	**2.34**	**2.93**	tr	tr	tr	tr	tr
94	4-Tert-Butylphenyl methyl ether	28.70	1669	tr	tr	tr	**1.39**	tr	tr	tr	tr	tr	tr
95	α-cadinol	28,75	1672	**0.4**	tr	tr	tr	tr	tr	tr	tr	tr	tr
96	Allospathulenol	29.07	1685	tr	tr	tr	**1.09**	tr	tr	tr	tr	tr	tr
97	Sesquichamene	29.11	1687	tr	0.11	tr	tr	tr	tr	tr	tr	tr	tr
98	Isospathulol	29.29	1692	tr	tr	tr	**3.09**	tr	tr	tr	tr	tr	tr
99	Cyclododecane	29.33	1695	tr	0.07	tr	tr	tr	tr	tr	tr	tr	tr
100	Alloaromadendrene	29,63	1711	tr	tr	tr	tr	tr	0.26	tr	tr	tr	tr
101	α-costal	29.74	1718	tr	tr	tr	tr	**1.23**	tr	tr	tr	tr	tr
102	α-copaen-11-ol	29.81	1719	tr	tr	tr	tr	0.19	tr	tr	tr	tr	tr
103	Trans-farnesol	29,97	1727	0.08	tr	tr	0.09	tr	tr	tr	tr	tr	tr
104	β-Oplopenone	30.05	1729	tr	tr	tr	**0.6**	**1.35**	tr	tr	tr	tr	tr
105	1-Amino-4-bromonaphalene	30.48	1750	tr	tr	tr	tr	0.27	tr	tr	tr	tr	tr
106	β-Elemenone	30.78	1764	tr	tr	tr	tr	**1.08**	tr	tr	tr	tr	tr
107	Isoaromadendrene epoxide	31.03	1777	tr	tr	tr	**0.92**	tr	tr	tr	tr	tr	Tr
108	Vitrenal	31.33	1793	tr	tr	tr	tr	**1.15**	tr	tr	tr	tr	tr
109	1-Pentadecen-8-yne	31.42	1796	tr	tr	tr	tr	0.09	tr	tr	tr	tr	tr
110	Hexahydro-farnesyl acetone	32.6	1855	tr	tr	tr	tr	0.06	tr	tr	tr	tr	tr
111	Acide n-Hexadecanoique	34.68	1989	tr	tr	tr	tr	tr	**0.78**	tr	tr	tr	tr
112	Oosane	35.29	1999	tr	tr	tr	tr	tr	tr	tr	tr	0.34	tr
113	Manoyl oxide	35.65	2003	tr	tr	tr	0.35	tr	tr	tr	tr	tr	tr
114	Trans-Phytol	37.59	2106	tr	tr	tr	tr	0.08	tr	tr	tr	tr	tr
115	Phytol	37.61	2108	tr	0.05	tr	0.02	tr	tr	tr	tr	tr	tr
116	Acide 9-Octadecenoique	37.90	2111	tr	tr	tr	tr	tr	**0.99**	tr	tr	tr	tr
118	Pentacosane	44.01	2425	tr	tr	tr	tr	tr	tr	tr	tr	0.35	tr
119	Heptacosane	47.8	1610	tr	tr	tr	tr	tr	tr	tr	tr	**0.9**	tr

Table 1: Percentage composition of essential oils from ten *Eucalyptus* species collected from different arboreta in Tunisia (Major and predominant compounds marked in bold form).

RI, KI were respectively Retention Index and Kováts Index calculated on a HP-5MS capillary column (30 m × 0.25 mm × 0.25 μm), tr: traces

E. rudis, E. camaldulensis, E. dumosa collected from the arboretum of Korbous (north East Tunisia); *E. transcontinentalis* and *E. dumosa* collected from the arboretum of Sidi Ismail (Sahel of Tunisia); *E. cinerea, E. maidenii* and *E. viminalis* collected from the arboretum of Souiniet, Aïn Draham (north West of Tunisia). Results reported in Table 1 indicated that major and predominant components of their essential oil were: α-pinene, Phellandrene, β-pinene, 1,8-cineole, Cis-Ocimene, γ-terpinene, α-terpinolene, Linalool, Dehydro-p-cymene, Isoamyl isovalerate, β-Thujone, Cis-Geraniol, 3-Methylene cycloheptane, Trans-pinocarveol, Trans-pinocarveol, Pinocarvone, Borneol, Terpinene-4-ol, Cyclohexanol, Linalyl propionate, α-terpineol, β-fenchyl alcohol, Trans-Piperitol, Cuminic aldehyde, Geraniol, Piperitone, Isothymol, Ethyl mesylate, Cuminyl alcohol, Methyl geranate, Bicycloelemene, Camphene, α-terpinene, Geranyl acetate, α-gurjunene, Bicyclogermacrene, Trans-caryophyllene, β-caryophyllene, Aromadendrene, γ-gurjunene, β-eudesmene, 1,4-Dimethyltertraline, Epiglobulol, Viridiflorol, γ-cadinene, Globulol, Ledene, β-eudesmol, Spathulenol, β-selinene, Isospathulenol, γ-selinene, t-muurolol, 4-Tert-Butylphenyl methyl ether, α-cadinol, Allospathulenol, Isospathulol, -costal, β-Oplopenone, β-Elemenone, Vitrenal, Isoaromadendrene epoxide, Acide n-Hexadecanoique, Acide 9-Octadecenoique and Heptacosane. Generally, these major components determine the biological properties of the essential oils. Additionally, results indicated that these major identified components in the 10 essential oils with pesticidal activity were in accordance with those extracted from various Eucalyptus species throughout the word [11,23-29]. Furthermore, our data provides a clear evidence that 1,8 cineole is the major constituent of the ten essential oils. Its relative proportions reached 82.82% for *E. transcantinentalis*, 79.44% for E. *dumosa*, 75.79% for *E. viminalis*, 75.64% for *E. maidenii* and 67.22% for *E. cinerea*. Such results were reported by Duke [30] who indicated that among the various components of *Eucalyptus* oil, 1,8-cineole is the most important one and is a characteristic compound of the genus *Eucalyptus*, and is largely responsible for a variety of its pesticidal properties.

Bioassays were designed to assess median lethal concentration LC_{50} (dose that kills 50% of the exposed insects). Probit analysis [31] was used to estimate LC_{50} values. Table 2 illustrated results of the ten essential oils reported on adults of different Tunisian strains of stored product insect pests.

Bioactive essential oils from *Artemisia* species

The Genus *Artemisia* L. comprises important medicinal plants which are currently the subject of phytochemical attention due to their biological and chemical diversity [34]. This genus contains over 500 species, which are mainly found in Asia, Europe and North America [35]. Le Floc'h, [36] reported that in Tunisia, the genus Artemisia contains six species: *Artemisia arborescens*, *Artemisia atlantica*, *Artemisia campestris Artemisia herba alba, Artemisia inculta,* and

Essential oils	Insect pests					
	E. cautella	*E. kuehniella*	*E. ceratoniae*	*Plodia interpunctella*	*C. hemipterus*	*O. surinamensis*
E. astringens	11.63 (8.7-14.7)	33.28 (8.29-65.08)	34.69 (27.8-41.7)	-	-	-
E. leucoxylon	11.28 (57.7-13.9)	24.59 (21.1-28.4)	32.91 (15.1-51.7)	-	-	-
E. lehmani	14.86 (11.7-17.6)	27.09 (22.0-32.0)	54.28 (49.6-60.2)	-	-	-
E. rudis	15.47 (10.9-19.6)	20.83 (4.0-42.3)	30.55 (6.4-55.3)	-	-	-
E. camaldulensis	11.07 (7.6-12.9)	20.46 (17.7-23.2)	34.08 (21.0-48.2)	-	-	-
E. dumosa	-	-	18.30 (13.1-23.0)	-	-	-
E. transcontinentalis	-	-	19.91 (18.0-21.9)	-	-	-
E. cinerea	13.09 (11.7- 17.6)	-	-	17.77 (13.9-24.7)	175.26 (169.4- 195.8)	17.033 (14.9- 19.9)
E.maidenii	12.5 (10.3-15.8)	-	-	9.08 (6.83-12.44)	92.07 (89.1-95.1)	17.61 (15.4-20.2)
E. viminalis	13.86 (10.1-21.9)	-	-	10.108 (8.32-13.98)	158.20 (152.5-162.1)	20.512 (18.29-23.4)

Table 2: LC_{50} values (µl/l air) of different essential oils extracted from different arboreta in Tunisia against various stored product insects [28,29,32,33]. LC_{50} (µl/ air) values calculated for mortality within 24 h of exposure at 25°C (95% lower and upper confidence limits are shown in parenthesis).

Artemisia vulgaris. The white wormwood, *Artemisia herba-alba* Asso is dwarf shrub that grows wild in arid areas of the Mediterranean basin, extending into northern Himalayas [37]. In Tunisia, *A. herba-alba* is growing wild in the southern arid zone [38]. Moreover, the wormwood or absinthe wormwood, *Artemisia absinthium* L., is a medicinal and aromatic bitter herb, which has been used as a medicine from ancient times [39]. *Artemisia* species essential oils have insecticidal or repellent properties [40-44].

In this section, we investigated the chemical composition of the essential oil from Tunisian *A. herba-alba* and *A. absinthium* (Table 3). In addition, we evaluated their fumigant efficacy, contact toxicity and repellency against the red flour beetle *Tribolium castaneum* (Herbst) and the *sawtoothed grain beetle*, *Oryzaephilus surinamensis (L.)* that are two of the most important beetle pests of stored products in Tunisia (Tables 4 and 5).

Major and predominant components from *A. absinthium* essential oil were: β-thujone (22.72%), Camphor (16.71%), 1,8 cineole (5.47%), Camphene (2. 37%), Borneol (1.77%), Pinocarvone (0.94%), Benzyl bromoacetate (0.71), m-cymene (0.63%) and Sabinyl acetate (0.43%). While, for *A. herba-alba* essential oil, major and predominant components were: 1,8-cineole (19.59%), Camphor (11.48%), α-pinene (5.4%), Camphene (2.63%), Borneol (2.29%), β-pinene (1.64%), α-terpineol (1.09%), Caryophyllene (0.99%), Bornyl acetate (0.72%) and m-cymene (0.48%).

Results reported in Table 3 showed similarity regarding chemical composition of the two essential oils. Results indicated quantitative and qualitative variations in the composition of the essential oils were observed. Results in Table 3 clearly demonstrated that both oils were rich in compounds known to possess insecticidal activity. Moreover, our data confirms previous works related to chemical composition of both essential oils [39,45,46].

Results demonstrated that for fumigant and contact tests, essential oils were toxic against the two beetles. Regarding, fumigant toxicity, results indicated that *A. herba-alba* oil was more effective against both insects compared to *A. absinthium* oil. This result could be attributed to its chemical composition. Indeed, highest percentages of α-pinene, β-pinene, 1.8-cineole and α-terpineol in *A. herba-alba* oil compared

N°	Compounds	RI	*A. absinthium*	*A. herba-alba*
1	Methylcyclopentane	2.42	0.21	0.36
2	1,3-cyclopentadiene,5-1,1 dimethylethyl	5.85	0.13	tr
3	Cis-salvene	6.38	0.02	tr
4	Tricyclene	8.24	tr	0.09
5	Delta-3-carene	8.25	0.15	0.10
6	**α-pinene**	8.62	0.29	**5.4**
7	**Camphene**	9.07	**2.37**	**2.63**
8	Verbenene	9.23	0.13	tr
9	Sabinene	9.83	0.07	tr
10	**β-pinene**	9.90	0.06	**1.64**
11	β-myrcene	10.40	tr	0.32
12	Psi-cumene	10.49	0.21	tr
13	α-terpinene	11.16	0.07	0.22
14	**m-cymene**	11.45	**0.63**	**0.48**
15	**1,8-cineole**	11.62	**5.47**	**19.59**
16	ɣ-terpinene	12.46	0.06	0.41
17	α-terpinolene	13.34	tr	0.17
18	Linalool	13.82	tr	0.25
19	**β-thujone**	14.00	**22.72**	tr
20	**Camphor**	15.19	**16.71**	**11.48**
21	**Pinocarvone**	15.61	**0.94**	tr
22	**Borneol**	15.81	**1.77**	**2.29**
23	Terpinene-4-ol	16.11	0.35	0.32
24	**α-terpineol**	16.54	tr	**1.09**
24	Myrtenal	16.56	0.14	tr
26	Myrtenol	16.67	0.22	tr
27	Verbenone	16.97	0.46	tr
28	Carvone	17.98	0.16	tr
29	Piperitone	18.26	0.33	tr
30	Chrysanthenyl acetate	18.38	**0.69**	tr
31	**Bornyl acetate**	19.05	0.25	**0.72**
32	Sabinyl acetate	19.26	**0.43**	tr
33	Benzyl bromoacetate	20.06	**0.71**	tr
34	**Caryophyllene**	22.65	tr	**0.99**
35	α- Caryophyllene	23.52	tr	0.15
36	Caryophyllene oxide	23.69	tr	0.11
37	Germacrene-D	24.21	0.27	tr
38	Bicyclogermacrene	24.58	0.15	tr
39	Spathulenol	26.62	0.09	tr
40	Oleic acid	39.84	tr	0.22

RI is the Retention Index calculated on a HP-5MS capillary column (30 m × 0.25 mm × 0.25 µm), tr: traces

Table 3: Percentage composition of essential oils from two Artemisia species collected from north Tunisia (Major and predominant compounds marked in bold form).

Bioassays	Essential oil	*T. castaneum*		*O. surinamensis*	
		LC_{50}	LC_{95}	LC_{50}	LC_{95}
Fumigant activity	*A. herba-alba*	359.681	1652.659	23.818	32.18
	A. absinthium	886.023	5625.500	42.795	80.181
Contact toxicity	*A. herba-alba*	0.261	2.291	0.209	1.963
	A. absinthium	1.432	133.323	0.242	16.864

Table 4: Lethal Concentrations LC_{50} and LC_{95} (µl/l air) of two *A. herba-alba* and *A. absinthium* essential oils against adults of *T. castaneum* and *O. surinamensis* [47]. LC_{50} and LC_{95} (µl/ air) values calculated for mortality within 24 h of exposure at 25°C.

Insects	Essential oils	Concentrations (µl/cm²)			
		0.09	0.19	0.29	0.39
T. castaneum	*A. herba alba*	20	7.5	27.5	40
	A. absinthium	92.5	97.5	90	92.5
O. surinamensis	*A. herba alba*	2.5	45	17.5	7.5
	A. absinthium	53.09	40	34.29	12.5

Table 5: Repellency (%) of *A. herba-alba* and *A. absinthium* essential oils against adults of *T. castaneum* and *O. surinamensis* after 24 h of exposure [47].

to *A. absinthium* oil (Table 3) conferred it best insecticidal potential against the two tested insect species. Indeed, the pesticidal activity essential oils has been due to various components such as 1,8-cineole, α-pinene and α-terpineol [27,48,49]. Concerning contact toxicity, results showed that the sawtoothed grain beetle *O. surinamensis* was more susceptible than the red flour beetle *T. castaneum*. Additionally, *A. herba-alba* oil was also more effective than *A. absinthium* oil. To summarize, results indicated that both *A. herba-alba* and *A. absinthium* essential oils were toxic against adults of the two beetles. Our data support the use of Tunisian Artemisia essential oils as grain protectants for the management of stored insect pests.

Results reported in Table 5 showed that the highest repellent activity was recorded with *A. absinthium* essential oil. Indeed, repellency reached respectively 92.5 and 53.09% for *T. castaneum* and *O. surinamensis* at the dose 0.09 µl/cm² after 24 h of exposure. This important repellency could be attributed to chemical composition of this oil. In this respect, the components as β-thujone, chrysanthenyl acetate and sabinyl acetate were responsible for the repellent activity of *A. absinthium* essential oil [50]. In addition, several researches reported the repellent activity of *A. absinthium* oil various insects such as fleas, flies and mosquitoes [51,52]. All those results valorize Tunisian *A. herba-alba* and *A. absinthium* essential oils as sources of biological active compounds. Thus, these species might be good candidates for further investigations in developing new control approaches and can be used as natural bio-insecticides instead of more toxic synthetic pesticides. Moreover, further investigations on other Artemisia species would be of interest.

Conclusion

The biological proprieties of the tested essential oils were consistent with results from other scientific studies. *Eucalyptus* and *Artemisia* essential oils from Tunisia were successfully applied against various stored product insect pests. As indicated above, some changes in chemical composition occur, these changes were directly linked to plant factors (genotype, climate, age of plantation, soil,…). However, standard protocols for bioassays and a database for collecting and organizing bioactivity data would be useful for more comprehensive study on bioactive component distribution through the word.

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