Essential oil composition, antioxidant and antibacterial activities of wild and cultivated Lavandula mairei Humbert

A. El Hamdaoui, F. Msanda, H. Boubaker, D. Leach, Isabelle Bombarda, Pierre Vanloot, N. El Aouad, A. Abbad, E.H. H Boudyach, F. Achemchem, et al.

To cite this version:
A. El Hamdaoui, F. Msanda, H. Boubaker, D. Leach, Isabelle Bombarda, et al.. Essential oil composition, antioxidant and antibacterial activities of wild and cultivated Lavandula mairei Humbert. Biochemical Systematics and Ecology, 2018, 76, pp.1 - 7. 10.1016/j.bse.2017.11.004 . hal-01930218

HAL Id: hal-01930218
https://amu.hal.science/hal-01930218v1
Submitted on 21 Nov 2018

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Distributed under a Creative Commons Attribution 4.0 International License
Essential oil composition, antioxidant and antibacterial activities of wild and cultivated Lavandula mairei Humbert

A. El Hamdaoui a, F. Msanda a,*, H. Boubaker b, D. Leach c, I. Bombarda d, P. Vanloot d, N. El Aouad a,c, A. Abbad f, E.H. Boudyach b, F. Achemchem g, A. Elmoslih b,g, A. Ait Ben Aoumarb, A. El Mousadika

a Laboratoire de Biotechnologies et Valorisation des Ressources Naturelles, Faculté des Sciences, Université Ibn Zohr, Agadir, Morocco
b Laboratoire de Biotechnologies Microbiennes et de Protection des Végétaux, Faculté des Sciences, Université Ibn Zohr, Agadir, Morocco
c Southern Cross Plant Science, Southern Cross University, Lismore 2480, NSW, Australia
d U-Marseille Univ, IMBE, BEC, Marseille, France
e Centre des Sciences et Techniques du Campus Universitaire Ait Melloul, Université Ibn Zohr, Agadir, Morocco
f Laboratoire de Biodiversité et Dynamiques des Ecosystèmes, Faculté des Sciences Semlalia, Université Cadi Ayyad, Marrakech, Morocco
g Laboratoire des Sciences de l’Ingénieur et le Management de l’Energie, Ecole Supérieure de Technologie, Agadir, Morocco

A B S T R A C T

Lavandula mairei is an endemic and rare plant species growing in the mountains from the southeast to the southwest of Morocco. It is an aromatic and medicinal plant widely used in traditional medicine for the treatment of various diseases. To our knowledge, no data are available on the chemical composition and the biological activities of L. mairei essential oils (EOs). The aim of this study was to investigate the effect of cultivation on the chemical composition, antioxidant and antibacterial activities of EOs isolated from L. mairei. The hydrodistilled oils obtained from wild and cultivated L. mairei were analyzed by GC/MS. Twenty-three compounds were identified representing more than 98% of both EOs (wild and cultivated). Oils were characterized by high amount of carvacrol (78.29 and 76.61% for wild and cultivated EO respectively). The antioxidant and antibacterial assays revealed that the two EOs tested showed significant activities. The results highlighted that cultivation affected neither the chemical composition nor the biological activities of L. mairei. Cultivation of L. mairei may constitute an alternative to the conservation of this species.

Keywords:
Lavandula mairei
Essential oils
Antioxidant
Antibacterial

1. Introduction

The genus Lavandula L. (Lamiaceae) is native to the Mediterranean region, Canary Islands and India, and it is now cultivated in different regions of the world (Palé-Paul et al., 2004). The EOs of a number of Lavandula species are of economic importance in perfumery and fragrance industry, aromatherapy (Shellie et al., 2002) and known to have various biological properties such as antibacterial activity (Cherrat et al., 2014; Djenane et al., 2012; Hanamanthagouda et al., 2010; Varona et al., 2013), antifungal activity (Adam et al., 1998; Angioni et al., 2006; Zuzarte et al., 2012, 2013), antioxidant activity (Carrasco et al., 2015; Cherrat et al., 2014; Viuda-Martos et al., 2011), insecticidal activity (Badreddine et al., 2015; Cosimi et al., 2009; Khosravi and Sendi, 2013) and anti-inflammatory activity (Hajhashemi et al., 2003; Zuzarte et al., 2013).

The genus Lavandula is represented in Moroccan flora by 9 species and subspecies of which 5 are endemic (Fennane et al., 2007). Among these endemic lavenders, Lavandula mairei Humbert is considered as a rare species (Fennane and Ibn Tattou, 1998). The wild plant grows in saharian, arid and semi-arid bioclimates, from the southeast to the southwest mountains of Morocco. It is a perennial shrub growing, usually, up to 0.40–0.80 m high with spike violet flowers. It is widely used in traditional medicine for the treatment of various diseases such as gastrointestinal ailments, microbial infection, cough and asthma (Abouri et al., 2012).

Morocco is one of the countries where production of medicinal plants is based on the harvesting in the wild and several plant species were becoming rare and sparse due to overexploitation and, aridity and to the endangered medicinal plant species lack of

* Corresponding author.
E-mail address: f.msanda@uiz.ac.ma (F. Msanda).
conservation actions (Abouri et al., 2012; Bellahktar et al., 1991). Therefore, cultivation of these medicinal plants might become a promising alternative for their conservation and sustainable use. Several studies have already shown the interest of culture practice on conservation of medicinal plants (Alaoui Jamali et al., 2014; El Abdouni Khiyari et al., 2014; El Bouzidi et al., 2013). Furthermore, the increasing concern on the development of resistance by bacteria to synthetic antibiotics has lead to an urgent need for alternative strategies for the control of bacterial infections. From this viewpoint, plants EOs have been suggested as alternative sources for bacterial pathogens control.

According to Fennell et al. (2004), transplanting a plant from a wild ecosystem to a cultivated field can affect the growth, the content and composition of secondary metabolites. Therefore, it is judicious to evaluate the effect of domestication and planting of medicinal plants, instead of the use of wild harvested plants, on plant growth, EOs composition and biological properties before any program of field cultivation.

To our knowledge, there is no report on the chemical composition and biological activities of L. mairei EO. Thus the aim of this study was to (i) determine the chemical composition and evaluate the antioxidant and the antibacterial properties of L. mairei EOs and (ii) investigate the effect of cultivation on EO composition and biological activities.

2. Materials and methods

2.1. Plant cultivation

The seeds of L. mairei were collected in southwest of Morocco, from Tafraoute village in June 2012. Seedlings were grown from seeds in 5 rows with 50 cm apart and 6 m length. For the first month, the crop was watered twice a week. For the next months the irrigation was carried with an interval of 15 or 21 days as needed. The experimental area is located in Faculty of Sciences, Agadir. The soil characteristics were pH (8.2), sand (29.0%), silt (38.5%), clay (32.5%), organic matter (1.8%), total nitrogen (0.9%), P2O5 (118.8 mg/kg), total CaCO3 (13.8%). The experimental area is characterized by an aride bioclimate with a mean rainfall of 236.8 mm/year and an average temperature of 18.5 °C. Irrigation was carried out as required.

2.1.1. Plant materials

The aerial parts of cultivated and wild L. mairei were harvested at flowering stage at the end of May 2014 and voucher specimens were deposited in the laboratory of Biotechnology and Valorization of Natural Resources, Faculty of Sciences, Ibn Zohr University, Agadir, Morocco, and referred as LM114 and LM214 for wild and cultivated plants respectively. Plant samples were air-dried in the shade and stored in the dark at 4 °C until use.

The seeds used for plant cultivation and the samples of wild plant material studied were collected from the same population of L. mairei (29°51'19.1" N, 8°54'51.6" W, elevation 1240 m), and the age of cultivated plants was 20 months.

2.1.2. Extraction of essential oil

The EOs of wild and cultivated L. mairei were obtained from dried aerial plant materials by hydrodistillation using a Clevenger type apparatus for 3 h. The EOs were dried over anhydrous sodium sulfate and stored in an amber bottle at 4 °C until used.

2.2. Gas chromatography/mass spectrometry (GC/MS) analyses

The analytical GC/MS system used was an Agilent GC/MSD system (Agilent Technologies 6890/5973) with helium (high purity) as the carrier gas at a constant linear velocity of 37 cm/s. The transfer line, ionization source and quadrupole temperatures were 280 °C, 230 °C and 150 °C respectively, operating at 70 eV ionization energy and scanning the m/z range 41–450. The column used was an Agilent DB5 MS capillary column (30.0 m × 0.25 mm ID x 0.25 µm film thickness) programmed from 60 °C to 246 °C at 3 °C/ min. EO samples (60 µL) were diluted with acetone (2 mL). The injection volume was 1.0 µL, the split ratio was 1:50 and the injector temperature was 260 °C. Three replicates were performed for each sample. Identification of the individual compounds was based on: (i) comparison with the mass spectra of authentic reference compounds where possible and by reference to WILEY275, NBS75K, and Adams terpene library (Adams, 2007); (ii) comparison of their retention indices (RI) on a DB5 (apolar, 5% phenyl polysilphenylenesiloxane), calculated relative to the retention times of a series of C-9 to C-24 n-alkanes, with linear interpolation, with those of authentic compounds or literature data (Adams, 2007). For semi-quantitative purposes, the normalized peak area of each compound was used without any correction factors to establish abundances.

2.3. Antioxidant activity

2.3.1. DPPH assay

The DPPH radical (2,2-diphenyl-1-picrylhydrazyl) scavenging ability was determined according to the method described by Şahin et al. (2004). Fifty microliter of the essential oil at various concentrations (0.01, 0.02, 0.04, 0.08, 0.16 and 0.32 mg/mL) diluted in methanol were added to 2 mL of DPPH methanol solution (60 μM). After 20 min incubation in darkness, at ambient temperature, the absorbance was measured at 517 nm. Quercetin was used as a positive control while methanol as a negative one. All analyses were carried out in triplicate and results were expressed as mean ± SD. The scavenging percentage of DPPH radical was calculated using the following formula:

\[
\text{Inhibition} \% = \left( \frac{A_0-A_S}{A_0} \right) \times 100
\]

Where A0 is the absorbance of the control and AS is the absorbance of the tested oils.

The sample concentration providing 50% inhibition (IC50 μg/mL) was calculated by plotting the inhibition percentages against the concentrations of the sample.

2.3.2. Reducing power determination

In this assay, antioxidant activity of the EOs was determined by using the potassium ferricyanide-ferric chloride method as described by Oyaizu (1986). The sample concentrations (in methanol) used were: 0.003, 0.005, 0.007, 0.009, 0.011, 0.013, 0.015 and 0.017 mg/mL. Quercetin was used as a reference compound and methanol as a negative control. The sample concentration providing 0.5 of absorbance (IC50) was calculated by plotting absorbance at 700 nm against the corresponding sample concentration. The test was carried out in triplicate and IC50 values were reported as means ± SD.

2.4. Antibacterial activity

2.4.1. Bacteria

The bacterial strains tested in this study included four Gram positive, namely Listeria innocua (CECT 4030), Listeria monocytogenes (CECT 4032), Staphylococcus aureus (CECT 976) and Bacillus subtilis (DSM 6633), and two Gram negative: Proteus vulgaris (CECT 484) and Pseudomonas aeruginosa (CECT 118). The standard bacterial species were cultivated in Tryptic Soy Agar (TSA) and incubated at 37 °C for 18 h under aerobic conditions. Original...
cultures are maintained at –70 °C in glycerol.

2.4.2. Antibacterial screening

The agar disc diffusion assay was employed for the determination of the essential oils antibacterial activity according to the method of Gachkar et al. (2007). As a positive control Ampicillin (25 μg/disc), Penicillin (10 μg/disc), Tetracycline (30 μg/disc), Amoxicillin (25 μg/disc) and Chloromphenicol (30 μg/disc) were used. The antibacterial activity was determined by measuring the diameter of the inhibition zone in millimeters with a digital caliper, and the results were expressed as mean ± SD. Three plates were used for each treatment as replications and the experiment was repeated twice.

2.4.3. Determination of the minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC)

The broth macrodilution method was used to determine the minimum inhibitory concentration (MIC) according to the NCCLS guidelines M07-A8 (NCCLS, 2009). All tests were performed in Tryptic Soy Broth (TSB) supplemented with Tween 80, at a final concentration of 0.5%, to enhance oil solubility (Moureya and Canillac, 2002). Fresh overnight cultures, in log phase, of the tested microorganisms were used to prepare the cell suspension at 10^6 CFU/mL. The test tubes were incubated aerobically at 37 °C for 24 h. MIC was defined as the lowest concentration of the assayed samples that produced 99.9% reduction in CFU/mL as compared with the control (Bosio et al., 2000). Positive and negative growth controls were included in every test. The test was performed in triplicate and the experiment was repeated twice.

2.5. Data analysis

Data were subjected to variance analyses (ANOVA) using STATISTICA software, ver. 6 (Stat-Soft, 2001, Créteil, France).

3. Results and discussion

3.1. Chemical composition

The yields of EOs obtained from aerial parts, were 1.00 ± 0.26% for wild plant and 1.22 ± 0.20% for cultivated plant on a dry weight basis (v/w). Cultivation did not greatly affect essential oil production. Twenty-three compounds were identified representing more than 98% in both cases (wild and cultivated) using GC/MS and retention indices (Table 1). EOs were characterized by a large amount of monoterpenes (90.65 and 90.96%) including oxygenated monoterpenes as major compounds (82.98 and 82.67%). Sesquiterpenes represented only 5.27 and 4.13% for wild and cultivated EO respectively. L. mairei EOs are characterized by high amount of carvacrol (78.29 and 76.61%) (Figs. 1 and 2) followed by terpinolene (2.96–3.20%), octen-3-ol (1.84–2.31%), cis-β-ocimene (1.72–1.27%), p-cymen-8-ol (1.81–1.16%), β-caryophyllene (1.45–1.76%) and

| Compounds | M⁺ (Parent Ion) | RI | % of Compound |
|-----------|-----------------|----|----------------|
| α-Pineën | 136 | 931 | 0.35 ± 0.02* |
| Octen-3-ol | 128 | 972 | 1.84 ± 0.04* |
| Octan-3-one | 128 | 984 | 0.45 ± 0.02* |
| β-Myrcène | 136 | 990 | 1.00 ± 0.07* |
| α-Phellandrenè | 136 | 1008 | 0.19 ± 0.02* |
| δ-3-Carene | 136 | 1012 | 0.54 ± 0.02* |
| α-Terpinènè | 136 | 1016 | 0.16 ± 0.02* |
| p-Cymènè | 132 | 1021 | 0.77 ± 0.02* |
| Limonène | 136 | 1025 | 0.31 ± 0.01* |
| cis-β-Ocimènè | 136 | 1042 | 1.72 ± 0.01* |
| trans-β-Ocimènè | 136 | 1051 | 2.31 ± 0.04* |
| Terpinolène | 136 | 1088 | 2.96 ± 0.02* |
| Linalool | 154 | 1096 | 0.33 ± 0.02* |
| Mentha-1,8-dien-4-ol | 154 | 1177 | 0.36 ± 0.02* |
| Terpinen-4-ol | 154 | 1178 | 0.45 ± 0.02* |
| p-Cymen-8-ol | 150 | 1184 | 1.81 ± 0.06* |
| α-Terpinolènè | 154 | 1191 | 0.38 ± 0.01* |
| Carvacrol methyl ether | 164 | 1244 | 1.36 ± 0.01* |
| Carvacrol | 150 | 1302 | 78.29 ± 0.08* |
| β-Caryophyllène | 262 | 1424 | 1.45 ± 0.02* |
| Spathulenol | 224 | 1581 | 1.51 ± 0.02* |
| Caryophyllène oxide | 216 | 1587 | 2.31 ± 0.04* |
| Manolyxolide | 290 | 2036 | 0.44 ± 0.02* |

| Monoterpenes hydrocarbons | 7.67 ± 0.36* | 8.29 ± 0.08* |
| Oxygenated monoterpenes | 82.98 ± 0.11* | 82.67 ± 0.11* |
| Sesquiterpenes hydrocarbons | 1.45 ± 0.02* | 1.76 ± 0.03* |
| Oxygenated sesquiterpenes | 3.82 ± 0.03* | 2.37 ± 0.03* |
| Oxygenated diterpenes | 0.44 ± 0.02* | Trb |
| Others | 2.29 ± 0.05* | 3.03 ± 0.10b |

The reported percentages of each compound were the mean value of three replicates for each population (wild and cultivated). Different letters after values mean statistically significant differences with p < 0.05.
Carvacrol methyl ether (1.36–3.86%). Previous studies have shown that carvacrol does not usually appear as a dominant compound in oils extracted from other Lavandula species. Thus, camphor and 1,8-cineole were the major components of essential oils from Lavandula stoechas from Tunisia (Badreddine et al., 2015) and Lavandula latifolia from Spain (Herraiz-Penalver et al., 2013; Muñoz-Bertomeu et al., 2007). Cherrat et al. (2014) have reported that 10s,11s-Himachala-3(12),4-diene, cubenol, methyl eugenol, δ-cadinene and myrtenyl acetate were the main constituents of Lavandula stoechas from north of Morocco, while Camphene, α-Pinene, limonene, eucalyptol, fenchone and camphor were the principal compounds of Lavandula stoechas essential oil from Spain (Carrasco et al., 2015). The major constituents of essential oils from Lavandula angustifolia from Cyprus were 1.8-cineole, borneol, camphor, terpineol and myrtenal (Chrysargyris et al., 2016). The essential oils of Lavandula pedunculata from Portugal are characterized by three chemotypes: 1,8-cineole; 1,8-cineole/camphor and fenchone (Zuzarte et al., 2010). Trans-α-necrodyl acetate, β-selinene, trans-α-necrodol, fenchone, cineole, viridiflorol and camphor were determined as the most abundant compounds of the essential oils extracted from Lavandula luisieri from Portuguese populations (González-Coloma et al., 2011). Linalool and linalyl acetate, were determined as the two major compounds of essential oils of Lavandula angustifolia from Greece (Hassiotis et al., 2014). Chemical composition of essential oils from Lavandula officinalis from Iran showed that α-pinene, menthol and camphor were the main components (Miri, 2015). Ouedrhiri et al. (2017) have reported that β-pinene, 1,8-cineole and fenchone were the principal compounds of Lavandula dentata from north of Morocco. However, as previously reported, carvacrol was the major constituent of EOs obtained from Moroccan and Tunisian L. multifida samples (Belhadj Mostefa et al., 2014; Bellakhdar et al., 1985; Douhri et al., 2014; Sellam et al., 2013) and from L. canariensis (Palá-Paúl et al., 2004).

The EOs composition reveals very similar profiles for wild and cultivated L. mairei, the percentage of various constituents showed very low variations and carvacrol remained the main constituent with more than 76% in both cases. The presence of carvacrol in very substantial proportions presents a special interest, indeed carvacrol...
andula accords to what has been reported for other species of the Lavandula genus; indeed the antioxidant capacity of L. angustifolia was only twice a value of quercetin, exhibiting a high power ability was only twice a value of quercetin, using two different and complementary assays: the DPPH (2,2-diphenyl-1-picrylhydrazyl) free radical scavenging and the IC50 (2004; Tepe et al., 2005; Wang et al., 2008). As reported previously, the high antioxidant/reducing power activities of the oils could be explained by their high content of the phenol, carvacrol (Alaoui Jamali et al., 2012; Kulisic et al., 2004; Sokmen et al., 2013).

### 3.2. Antioxidant activity

L. mairei EOs were screened for their antioxidant activities in vitro using two different and complementary assays: the DPPH (2,2-diphenyl-1-picrylhydrazyl) free radical scavenging and the reducing power determination. The obtained results (Table 2) showed that both EOs exhibited antioxidant activity across the two testing methods. The concentrations that led to 50% inhibition or effectiveness (IC50) are given in Table 2. The lower IC50 values reflected better protective action. For the DPPH assay the IC50 value obtained was 107.54 ± 10.60 μg/mL for wild plant and 112.33 ± 2.30 μg/mL for the cultivated plant but they were less effective than quercetin used as positive control, (IC50 = 166 ± 0.20 μg/mL). For ferric reducing ability both oils showed very high activity; IC50 = 5.22 ± 2.3 μg/mL for wild plant and IC50 = 4.5 ± 0.80 μg/mL for the cultivated plant, values relatively comparable to those obtained for quercetin, used as antioxidant standard, IC50 = 3.16 ± 0.05 μg mL⁻¹. The L. mairei EOs IC50 value of reducing power ability was only twice a value of quercetin, exhibiting a high reducing power. The degree of antioxidant activity was variable in Lavandula genus; indeed the antioxidant capacity of L. mairei oils accords to what has been reported for other species of the Lavandula genus (Cherrat et al., 2014; Mori, 2015; Mohammed and Atik, 2011). However, Miliauskasa et al. (2004) detected weak antioxidant activity of EO obtained from L. angustifolia. Also of interest, our results highlighted that cultivation did not greatly affect the antioxidant property of L. mairei, since the obtained values did not differ significantly between wild and cultivated plants.

As reported previously, the high antioxidant/reducing power activities of the oils could be explained by their high content of the phenol, carvacrol (Alaoui Jamali et al., 2012; Kulisic et al., 2004; Polato et al., 2013; Roberto and Baratta, 2000; Sokmen et al., 2004; Tepe et al., 2005; Wang et al., 2008).

3.3. Antibacterial activity

The EOs from wild and cultivated L. mairei were screened against four Gram (+) and two Gram (-) bacteria. Both EOs showed antibacterial property on all tested bacteria with no significant difference between wild and cultivated plant (Table 3). Indeed, the EOs of wild and cultivated L. mairei inhibited the growth of tested bacterial strains with an inhibition zone diameter varying from 23.5 to 35.6 mm. The maximum activity was against L. innocua (35.3–34.6 mm) and L. monocytogenes (35.6–34.6 mm). P. vulgaris (23.5–24.0 mm) and S. aureus (24.5–23.5 mm) were the less sensitive strains. Overall, L. mairei EOs showed a better antibacterial potential compared to the positive controls. For example, P. vulgaris which is totally resistant (0 mm) to Ampicillin (Am 25), Penicillin (P10), Amoxicilline (Ax25) and slightly sensitive (9 mm) to Tetra-cycline (Te30) is sensitive to EOs obtained from the aerial parts of wild and cultivated L. mairei (Table 3). Our results were in accordance with results previously reported on L. angustifolia (Djenane et al., 2012), L. stoechas (Cherrat et al., 2014) L. hybrida super (Varona et al., 2013) and L. bipinnata (Hanamanthougaarda et al., 2010).

3.4. Determination of MIC and MBC

The antibacterial activity of EOs of wild and cultivated L. mairei was studied by determining their MIC and MBC values by using broth macrodilution method according to the NCCLS guidelines M07-A8 (NCCLS, 2009). As shown in Table 4, the investigated L. mairei EOs exhibited remarkable antimicrobial activity against all tested bacteria, with MIC values ranging from 0.60 to 1.20 mg/mL. Both EOs (wild and cultivated) showed a significant antibacterial activity against Gram positive as well as Gram negative bacteria (Table 4). The MBC values of the two oils were similar or even higher than the MIC values, with MIC/MBC ratio very close to 1, confirming their bactericidal activity.

The best antibacterial activity (MIC = 0.60 mg/mL) was shown against B. subtilis and P. aeruginosa. The weakest activity was observed against S. aureus (MIC = 1.20 mg/mL). L. mairei EOs can...
thus be used as effective antibacterial agent against several bacterial species.

The strong antibacterial activity of the EOs of wild and cultivated *L. mairei* can be attributed to the presence of high concentration of oxygenated monoterpenes (carvacrol: 78.29–76.61%). Indeed, plants EOs with high amounts of carvacrol are known to possess antibacterial activity (Alaoui Jamali et al., 2014; Calo et al., 2015; El Abdouni Khiyari, M., Kasrati, A., Alaoui Jamali, C., Zeroual, S., Markouk, M., 2014. Phytochemical analysis and antibacterial effects of *Lavandula multi-flora* L. from Morocco. Ind. Crops Prod. 45, 125–135). Some results were reported for wild and cultivated *Achillea ageratum* and *Thymus* spp. (El Bouzidi et al., 2013).

### 4. Conclusions

To the best of our knowledge, the composition and the biological activities of *L. mairei* EOs are reported for the first time. This study revealed that the EOs of this endemic and rare species is rich in carvacrol (more than 76%) as a component of particular biological importance, making *L. mairei* EO as a potential industrial source of carvacrol. Our results highlighted that EOs from the cultivated samples maintained their biological activity with respect to the wild population. Therefore, cultivation may constitute an alternative solution to conservation of this valuable and threatened medicinal plant.

### Conflicts of interest

We declare that we have no conflict of interest.

### Acknowledgements

The authors wish to thank Mr Mike Russel, Plant Sciences, Southern Cross University, Lismore NSW, Australia, for running the GC/MS profiles.

### Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.bse.2017.11.004.

### References

Abouri, M., El Mousadik, A., Msanda, F., Boubaker, H., Saadi, B., Cherifi, K., 2014. A ethnobotanical survey of medicinal plants used in the Tata Province, Morocco. Int. J. Med. Plants. Res. 1 (7), 99–123.

Adam, K., Aldoriti, S., Stella, K., Thomas, L., Minas, A., 1998. Antifungal activities of *Origanum vulgare* subsp. hirtum, *Mentha spicata*, *Lavandula angustifolia*, and *Salvia fruticosa* essential oils against human pathogenic fungi. J. Agric. Food Chem. 46 (5), 1739–1745.

Adam, R.P., 2007. Identification of Essential Oil Components by Gas Chromatography/Mass Spectrometry, fourth ed. Ed. Allured Publ. Corp, Carol Stream, IL.

Alooui Jamali, C., El Bouzidi, L., Bekkouche, B., Hassani, L., Markouk, M., Wohlmuth, H., Leach, D., Abdab, A., 2012. Chemical composition, antioxidant and anti candidal activities of essential oils from different wild Moroccan Thymus species. Chem. Biodivers. 9, 1188–1197.

Belhadj Mostefa, M., Kabouche, A., Abaza, I., Bouajri, T., Kabouche, Z., 2014. Chemotypes investigation of *Lavandula essential oils growing at different North African soils. J. Mater. Environ. Sci. 5 (6), 896–1901.

Bellalghdir, J., Berrada, M., Denier, C., Holeman, M., Idilír, A., 1985. Comparative chemical study of the essential oils of ten populations of *Lavandula multiflora* L. from Morocco. Birunia 1, 95–106.

Bellalghdir, J., Cazeneuve, R., Fievetrin, J., Younus, C., 1991. Repertory of standard herbal drugs in the Moroccan Pharmacopeia. J. Ethnopharmacol 35 (2), 123–142.

Bosio, K., Avanzini, C., D’Avolio, A., Ozino, O., Savoia, D., 2000. In vitro activity of propolis against Streptococcus pyogenes. Lett. Appl. Microbiol. 31 (2), 174–177.

Calo, J.R., Crandall, P.G., O’Bryan, C.A., Ricke, S.C., 2015. Essential oils as antimicrobials in food systems - a review. Food Control 54, 1116–1127.

Carrasco, A., Ortiz-Ruiz, V., Martinez-Gutierrez, R., Tomas, V., Tudela, J., 2015. *Lavandula stoechas* essential oil from Spain: aromatic profile determined by gas chromatography-mass spectrometry, antioxidant and lipoygenase inhibitory bioactivities. Ind. Crops Prod. 73, 16–27.

Charrat, L., Espina, L., Bakkali, M., Pagán, R., Laglaoua, A., 2014. Chemical composition, antioxidant and antimicrobial properties of *Mentha pulegium*, *Lavandula stoechas* and *Satureja calamintha* Scheele essential oils and an evaluation of their bactericidal effect in combined processes. Innov. Food Sci. Emerg. 22, 221–229.

Chrysargyris, A., Panayiotou, C., Tzortzakis, K., 2016. Nitrogen and phosphorus levels affected plant growth, essential oil composition and antioxidant status of lavender plant (*Lavandula angustifolia* Mill.). Ind. Crops Prod. 83, 577–586.

Cosimi, S., Rossi, E., Cioni, P.L., Panayiotou, C., Tzortzakis, N., 2016. Nitrogen and phosphorus in *Lavandula stoechas*, *Satureja montana*, *Satureja* subsp. *thymifolia* and *Satureja* subsp. *felinae*. J. Mater. Environ. Sci. 5 (6), 1896–2014.

Djenane, D., Aïder, M., Yangüela, J., Idir, L., Gmez, D., Roncal, M., 2016. Phytochemical and antibacterial activity of essential oil of *Lavandula multiflora* L. Int. J. Innovation Sci. Res. 1 (2), 116–126.

El Abdouni Khiyari, M., Kasrati, A., Alaoui Jamali, C., Zeroual, S., Markouk, M., Wohlmuth, H., Leach, D., Abdab, A., 2014. Cultivation and the application of inorganic fertilizer modifies essential oil composition in two Moroccan species of *Thymus*. Ind. Crops Prod. 62, 113–118.

Angioni, A., Barra, A., Coroneo, V., Dessi, S., Cabras, P., 2006. Chemical composition, seasonal variability, and antifungal activity of *Lavandula stoechas* L. spp. stoechas essential oils from stem/leaves and flowers. J. Agric. Food Chem. 54, 4366–4370.

Badreddine, B.S., Olfa, E., Samir, D., Hinia, C., Labhib, B.J., 2015. Chemical composition of *Rosmarinus* and *Lavandula essential oils and their insecticidal effects on *Orgyia trogolepis* (Lepidoptera, Lymantriidae). Asian J. Crop. Trop. Med. 8 (2), 98–103.

El Bouzidi, L., Abdab, A., Hassani, L., Farragh, A., Abdab, A., 2014. Cultivation and the application of inorganic fertilizer modifies essential oil composition in two Moroccan species of *Thymus*. Ind. Crops Prod. 62, 113–118.

Wohlmuth, H., Leach, D., Abdab, A., 2012. Chemical composition, antioxidant and antimicrobial properties of *Mentha pulegium*, *Lavandula stoechas* and *Satureja calamintha* Scheele essential oils and an evaluation of their bactericidal effect in combined processes. Innov. Food Sci. Emerg. 22, 221–229.

Chrysargyris, A., Panayiotou, C., Tzortzakis, K., 2016. Nitrogen and phosphorus levels affected plant growth, essential oil composition and antioxidant status of lavender plant (*Lavandula angustifolia* Mill.). Ind. Crops Prod. 83, 577–586.

Cosimi, S., Rossi, E., Cioni, P.L., Canale, A., 1999. Bioactivity and qualitative analysis of some essential oils from Mediterranean plants against stored-product pests: evaluation of repellency against *Sitophilus zeamais* Motschulsky, *Cryptolestes ferrugineus* (Stephens) and *Tenebrio molitor* (L.). J. Stored Prod. Res. 45, 125–132.

Djenane, D., Aïder, M., Yangüela, J., Idir, L., Gmez, D., Roncal, P., 2012. Antioxidant and antibacterial effects of *Lavandula and Mentha essential oils in minced beef inoculated with *E. coli* O157:H7 and *S. aureus* during storage at abuse refrigeration temperature. Meat Sci. 92, 667–674.

Dormain, H.J.D., Deans, S.G., 2000. Antimicrobial agents from plants, antibacterial activity of plant volatile oils. J. Appl. Microbiol. 88, 308–316.

Douiri, B., Douiri, H., Farah, A., Idaomar, M., Senbaj, N.S., Abrini, J., 2014. Phytochemical analysis and antibacterial activity of essential oil of *Lavandula multiflora* L. Int. J. Innovation Sci. Res. 1 (2), 116–126.

El Abdouni Khiyari, M., Kasrati, A., Alaoui Jamali, C., Zeroual, S., Markouk, M., Wohlmuth, H., Leach, D., Abdab, A., 2014. Chemical composition, antioxidant and insecticidal properties of essential oils from wild and cultivated *Salvia acheri* subsp. *blancoana* (Webb. & Helder), an endemic, threatened medicinal plant in Morocco. Ind. Crops Prod 57, 106–109.

El Bouzidi, L., Abdab, A., Hassani, L., Pattarsi, K., Leach, D., Markouk, M., Legendre, L., 2014. Biological properties of *Lavandula multi-flora* L. from Morocco. Ind. Crops Prod. 45, 125–135.
