SHST
Horticulture and Forestry Society of Transylvania

Slimani C *et al.* (2022)
Notulae Scientia Biologicae
Volume 14, Issue 1, Article number 11172
DOI:10.15835/nsb14111172
Research Article

NSB
Notulae Scientia Biologicae

Chemical composition and evaluation of biological effects of essential oil and aqueous extract of *Lavandula angustifolia* L.

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Abstract

The present work was carried out to evaluate the phenolic compounds, the antibacterial, antifungal and antioxidant activities of essential oil (EO) and aqueous extract (AE) of *Lavandula angustifolia* L. The extracts were obtained by hydrodistillation, and by decoction method using water, then, total phenolics, flavonoids and condensed tannins were determined using Folin-Ciocalteu, Aluminium chloride, and Bate-Smith reaction methods, respectively. Afterward, the antibacterial activity was evaluated using the borth microdilution and, the antifungal activity was discussed using dilution technique in solid medium. To estimate the antioxidant effect of these extracts, the Total Antioxidant Capacity and DPPH scavenging methods were performed. Results of phytochemical analysis of AE showed that total phenolics, flavonoids and condensed tannins were 67.967 ± 0.139 mg GAE/g DW, 53.578 ± 0.418 mg QE/g DW and 9.194 ± 0.323 mg/g DW, respectively. In addition, spectral analysis by Gas Chromatography of EO showed the presence of four main components in oil lavender: Linalool (29.95%), Linalyl acetate (18.86%), ρ-cymene (14.68%), and α-Campholenal (10.26%). Furthermore, the antibacterial test showed that *Staphylococcus aureus* and *Pseudomonas aeruginosa* were the most resistant compared to the other tested strains. Also, it appears that EO had greater antifungal activity compared to AE, and the both showed significant antioxidant potential. These eminent results showed that the use of *L. angustifolia* L. as an anti-infective in traditional environments is justified and that it should be studied more widely in order to explore its potential.

Keywords: antibacterial activity; antifungal activity; antioxidant activity; chemical composition; *Lavandula angustifolia* L.

Received: 10 Jan 2022. Received in revised form: 14 Mar 2022. Accepted: 15 Mar 2022. Published online: 17 Mar 2022.
From Volume 13, Issue 1, 2021, Notulae Scientia Biologicae journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

Abbreviations: EO-Essential oil; AE-aqueous extract; mL-Milliliter; g-Gram; mg-milligrams; h-Hour; °C-Celsius degree; GAE-Gallic acid equivalent; %-Percentage; min-minutes; AA-Ascorbic acid; *E. coli-Escherichia coli*; QE-Quercetin equivalent; *S. aureus-Staphylococcus aureus*; *E. faecalis-Enterococcus faecalis*; *P. aeruginosa-Pseudomonas aeruginosa*; *F. oxysporum-Fusarium oxysporum*; MIC-Minimal Inhibitory Concentration; LB-Lysogeny Broth; MBC-Minimal Bactericidal Concentration; PDA-Potato Dextrose Agar; BHT-Butylated hydroxytoluene

Introduction

Since antiquity, medicinal plants have always been part of basic human knowledge (Aquaron, 2015). Today, herbal preparations, also known as alternative or complementary medicine, are gaining a lot of popularity (Qidwai and Ashfaq, 2013), and increased interest in their use has encouraged more detailed studies of plant resources (Bagiu *et al.*, 2012). In modern societies there are a strong trend towards natural products, whether for health care, beauty or as food additives, aromas, preservatives, or spices (Bachiri *et al.*, 2017). In addition, the use of natural substances as antimicrobial and antioxidants agents could help to mitigate negative impact of chemical inputs on food webs, human health, and environment (Bachiri *et al.,* 2017). Several bioactive compounds have been reported for lavender, such as polyphenols, anthocyanins, and carotenoids that act as antioxidants in human body (Bachiri *et al.*, 2015). The essential oil of lavender is mainly composed of monoterpenes (the C10 class of isoprenoids), and is produced and stored in the glandular trichomes, which cover the surface of the aerial parts (both leaves and inflorescence) of the plant. Lavender main compounds responsible for the typical aroma are linalool, linalylacetate, 1,8-cineole, ocimene, terpene, and camphor (Haddanpouraghdam *et al.*, 2011). Essential oil of lavender has antiseptic and anti-inflammatory, analgesic, anti-fungal and bactericidal properties because it is rich in terpenes (Rafie *et al.*, 2016; Nikšić *et al.*, 2017; Wells *et al.*, 2018; Yuan *et al.*, 2019; Danila *et al.,* 2021). The aim of our work is to exploit the potential of *L. angustifolia* aqueous extract and essential oil in order to highlight their antimicrobial, antifungal, and antioxidant activities.

Materials and Methods

Plant material

Plant material consists of *L. angustifolia* L. aerial part collected from the botanical garden of National School of Agriculture, Meknes. The harvested part was dried at 45 °C in order to preserve the integrity of their molecules as much as possible. Also, many studies showed that the macro and the micronutrients, together with the phenolic compounds were not degraded when subjected to temperatures of 45 °C (Reis *et al.,* 2013; Nguyen *et al.,* 2018; Gustavo *et al.*, 2021). The plant was ground with a laboratory mortar and were sieved to obtain a fine powder, used for extraction.

Preparation of extracts

The essential oil (EO) was obtained by hydrodistillation, and the aqueous extract (AE) was obtained using distilled water as solvent. Fifteen grams of powder were boiled for 15 min according to the plant:solvent ratio of 1.5/10 (w/v). The solvent was removed under reduced pressure, and the resulting crude extract was stored at 4 °C in obscurity prior to use. It appears that the use of aqueous plant extracts is promising given their effectiveness and environmental safety. The aqueous extracts are also cheaper and cost-effective compared to other extracts prepared with organic solvents (methanol, ethanol, etc.).

Total phenols content

Total phenolic content of AE was performed according to the Folin Ciocalteu's method (Singleton, 1985). 200 µl of the extract was mixed with 1.5 mL of 10% (v/v) Folin Ciocalteu reagent. After 5 min, 1.5 mL of 5% (w/v) sodium carbonate was added. The absorbance was measured at 725 nm after 2 h of incubation. The concentration of total polyphenolics was calculated based on a calibration curve previously performed with the standard gallic acid. Results were expressed as mg of gallic acid equivalent (GAE)/g of extract.

Total flavonoids quantification

Total flavonoids content in AE was determined as described by Barros *et al.* (2011). Briefly, 1 mL of AE was mixed with 0.3 mL of 5% (w/v) $NaNO_2$. After 5 min, 0.3 mL of 10% (w/v) $AlCl_3$ were added. After 6 min, 2 mL of (1 M) NaOH were added, then, the volume of the mixture was made up to 10 mL with distilled water. The absorbance was measured at 510 nm. Total flavonoids were calculated from the calibration curve established with quercetin standard. Results were expressed as milligrams of quercetin equivalent/gram of extract (mg EQ/ g of extract).

Condensed tannins content

Condensed tannins were performed using Bate-Smith reaction (Stonestreet, 1966). Briefly 1 mL of AE was mixed with 0.5 mL of distilled water and 1.5 mL of 37% hydrochloric acid. The mixture was heated for 30 min in a water bath at 100 °C. The optical density "OD" was measured at 550 nm. The difference in OD between the hydrolysed tube and the control (tube at room temperature) corresponds to the amount of tannins present in the extract by the following relation:

$$\text{Tannins (mg/mL)} = 19{,}33 \text{ X } [\text{ODhydrolysis} - \text{ODControl}] \qquad (1)$$

Chromatographic analysis of L. angustifolia essential oil

Chromatographic analysis of *L. angustifolia* essential oils was performed on a gas chromatograph with electronic pressure control, type Hewlett Packard (HP 6890) equipped with a HP- 5MS capillary column (30 m x 0.25 mm, film thick- ness 0.25 µm). The injection mode was split (split ratio: 1/50, flow rate: 66 mL/min) and the injected volume was about 1 µL. Nitrogen was used as carrier gas with a flow rate of 1.7 mL/min. The column temperature was programmed from 50 to 200 °C at a heating rate of 4 °C/min, during 5 min. The apparatus was controlled by a "ChemStation" computer system. The identification of the components is based on the comparison of their mass spectra (GC/MS), respective with spectra of the library NIST 98, of the bibliography and based on calculation of Retention Index (RI) (Adams, 2017).

Antibacterial activity

The target bacterial strains used incorporated four aerobic and pathogenic strains: *Escherichia coli* (ATCC 25922), *Staphylococcus aureus* (ATCC 29213), *Pseudomonas aeruginosa* (ATCC 27853), *Enterococcus faecalis* (ATCC 51299) and a fungus *Fusarium oxysporum* ssp. f. *albidinis* (Foa). This lastwas isolated from the spines of palm trees (*Phoenix dactylifera*) affected with Bayoud brought from the region of Tafilalt in southern Morocco. The preparation of the test germ culture was carried out on the Lysogeny Broth (LB) medium for the bacterial strains and on the Potato Dextrose Agar (PDA) medium for the fungus. These cultures were incubated at the optimum growth temperature for each target strains.

Determination of the MIC

The Minimal Inhibitory Concentration (MIC) was defined as the lowest concentration of the extract that inhibits the bacterial growth. For its determination, the broth microdilution was performed. The microplates were then incubated at 37 °C for 24 h. After incubation, 10 µl of resazurine were added to reveal bacterial growth (Bouhdid *et al.*, 2009).

Determination of the MBC

To determine the Minimal Bactericidal Concentration (MBC), 3 µL of negative wells were deposited on the surface of LB agar plate and incubated at 37 °C for 24 h. MBC had been considered as the lowest concentration yielding a negative visible growth. The MBC/MIC ratio was also calculated to highlight the nature of the antibacterial effect (Levison, 2004).

Antifungal activity

Dilution method in solid medium was used to evaluate the antifungal activity (Moulari, 2005). The emulsification of extract was realized using agar solution 0.2% (Remmal *et al.,* 1993). 1 mL of each extract was mixed with 13 mL of PDA medium to give final concentrations of 1/100, 1/250, 1/500, 1/1000, 1/2000, 1/3000, 1/5000 (v/v). The seeding was done. Petri dishes (controls and tests) were incubated for 7 days. Diameters of filamentous fungal colonies were measured to calculate the inhibition rate I '(%) (Kordalis *et al.*, 2003). This rate is calculated according to the equation:

$$I'(\%) = \frac{dC-dE}{dC} \times 100 \qquad (2)$$

with:

- I'(%) = Inhibition rate expressed as a percentage;
- dC = Colony diameter in boxes "positive control";
- dE = Colony diameter in the boxes containing the plant extract.

The essential oil is:

- Very active when the inhibition rate I' is between 75 and 100 %. The fungal strain is very sensitive
- Active when the inhibition rate I' is between 50 and 75%. The fungal strain is sensitive;
- Moderately active when the inhibition rate I' is between 25 and 50% and the strain is limited;
- Little or no active when the inhibition rate I' is between 0 and 25% and the strain is resistant.

Evaluation of the antioxidant activity

DPPH assay

The DPPH (1,1-diphenyl-2-picrylhydrazyl) scavenging method was used to evaluate the antioxidant effect of *L. angustifolia* extracts (Brand-Williams *et al.*, 1995). For the extracts, a serial dilution was prepared from a solution of 4 mg/mL for AE and 20 µl/mL for EO prepared in methanol. Then, 1 mL of each dilution was added to 1 mL of DPPH (0.004%) for AE and to 2 mL of DPPH for EO. The mixture was left in dark for 30 min and the discoloration compared to the negative control containing only the DPPH solution was measured at 517 nm following the equation:

$$\text{Antioxidant activity (\%)} = \frac{\text{Abs DPPH} - \text{Abs final}}{\text{Abs DPPH}} \times 100 \qquad (3)$$

The antioxidant activity of these extracts was determined from their half-maximal inhibitory concentration (IC_{50}). It is the concentration necessary to reduce 50% of radical DPPH (Hebi *et al.*, 2016).

Total antioxidant capacity test

The phosphomolybdenum technique was also used. It is a quantitative analysis to study the rate of reduction reaction between an antioxidant and an oxidant. Briefly 0.3 mL of each extract) was added to 3 mL of a reagent composed of H_2SO_4, NaH2PO4, and ammonium molybdate. The screwed tube was incubated at 95 °C for 90 min. After cooling, the absorbance was measured at 695 nm. Results were expressed in mg equivalent ascorbic acid/gram of extract (mg EAA/g) from a calibration curve range, carried out by ascorbic acid standard (Prieto *et al.*, 1999).

Statistical analysis

The data was analysed statistically (means calculation, variance analysis, standard deviation) to find the existing variability between the two extracts used. A comparison test of averages was done whenever there was a significant factor effect studied by the ANOVA.

For the percentage results, we used a transformation to satisfy the conditions of normality of distributions and equality of variances (Gulumser *et al.*, 2006). This angular transformation was carried out according to the following formula:

$$Y = \text{Arcsin}\sqrt{5x/100} \qquad (4)$$

Results

Yields of L. angustifolia extracts

The yields of extracts were presented in Table 1. Thus, the EO had a yellow to orange colour, a strong odour with a yield of 2.13%, and the AE presented a dark coloured paste with a percentage of 21.68%.

Table 1. Yield of aqueous extract and essential oil of *L. angustifolia*

Extracts	Yields (%)
Essential oil	2.13
Aqueous extract	21.68

Phytochemical determination of extracts

Results from the phenolic content, flavonoids and condensed tannins of the AE were showed in Table 2. The values were 67.967 mg GAE/g, 53.578 mg QE/g and 9.194 mg/g respectively.

Table 2. Content of polyphenols, flavonoids and condensed tannins of the aqueous extract of *L. angustifolia*

Molecules	Extracts
Polyphenols	67.967 ± 0.139 (mg EAG/ g DW)
Flavonoids	53.578 ± 0.418 (mg EQ/ g DW)
Condensed tannins	9.194 ± 0.323 (mg/g DW)

Chemical composition of the essential oil

Twenty-two components were characterized, representing 99.1% of the total oil components detected, which are listed in table 3 with their percentage composition and retention index. Chemical identification and quantitative estimation of lavender oil showed four main components: Linalool (29.95%), Linalyl acetate (18.86%), ρ-cymene (14.68%), and α-Campholenal (10.26%).

Antibacterial activity of L. angustifolia

Determination of the MIC

MIC values of extracts against the different bacterial strains studied were given in Tables 4 and 5. It was found that the MIC obtained from EO was ranged from 8 and 4%. In contrast, the MIC values of the AE was ranged from 200 and 100 mg/mL. Based on these results, the highest MIC (8%) of EO was observed for *S. aureus* and the lowest one (4%) was observed against *E. faecalis, E. coli* and *P. aeruginosa*. For the AE, the highest MIC (200 mg/mL) was observed against *P. aeruginosa* and the lowest one (100 mg/mL) was observed against *E. coli*, *S. aureus* and *E. faecalis*.

Table 3. Main components of *L. angustifolia* essential oil along with their Retention Index (RI)

Compound	Formula	Retention Index	Area peak (%)
α-Thujene	$C_{10}H_{16}$	926	1.05
α-Pinene	$C_{10}H_{16}$	940	0.54
β-pinene	$C_{10}H_{20}$	979	1.57
δ-3-carene	$C_{10}H_{16}$	1013	0.22
p-cymene	$C_{10}H_{14}$	1022	14.68
1,8-cineole	$C_{10}H_{18}O$	1034	2.84
cis-linalool oxide	$C_{10}H_{18}O_2$	1076	0.41
Linalool	$C_{10}H_{16}$	1088	29.95
α-Campholenal	$C_{10}H_{16}O$	1137	10.26
Camphor	$C_{10}H_{16}O$	1147	0.66
Isoborneol	$C_{10}H_{18}O$	1158	2.65
3-thujanol	$C_{10}H_{18}O$	1167	0.53
Lavandulol	$C_{10}H_{18}O$	1173	0.34
Terpinen-4-ol	$C_{10}H_{18}O$	1180	1.3
Nerol	$C_{10}H_{18}O$	1214	0.11
Piperitone	$C_{10}H_{16}O$	1232	1.84
Linalyl acetate	$C_{11}H_{22}O_2$	1239	18.86
Linalyl acetate	$C_{12}H_{20}O_2$	1258	0.37
Geranial	$C_{10}H_{16}O$	1269	2.3
Neryl acetate	$C_{12}H_{20}O_2$	1341	0.55
Geranyl acetate	$C_{12}H_{20}O_2$	1359	0.97

Table 4. MIC of *L. angustifolia* essential oil against different microbial strains

EO (%) / Strains	32	16	8	4	2	1	0.5	0.25	0.12	0.06	0.03	C
E. coli	-	-	-	-	+	+	+	+	+	+	+	+
S. aureus	-	-	-	+	+	+	+	+	+	+	+	+
P. aeruginosa	-	-	-	-	+	+	+	+	+	+	+	+
E. faecalis	-	-	-	-	+	+	+	+	+	+	+	+

-: Absence of bacterial growth; +: Presence of bacterial growth; EO: Essential Oil; C: Control.

Table 5. MIC of the aqueous extract of *L. angustifolia* against the different microbial strains studied

AE (mg/mL) / Strains	200	100	50	25	12.5	6.25	3.12	1.56	0.78	0.30	0.09	C
E. coli	-	-	+	+	+	+	+	+	+	+	+	+
S. aureus	-	-	+	+	+	+	+	+	+	+	+	+
P. aeruginosa	-	+	+	+	+	+	+	+	+	+	+	+
E. faecalis	-	-	+	+	+	+	+	+	+	+	+	+

- Absence of bacterial growth; +: Presence of bacterial growth; AE: Aqueous Extract; C: Control

Determination of MBC

The results of MBC were presented in Table 6. For EO, it was found that MBC/MIC ratio was less or equal to 2%, therefore, our oil had a bactericidal effect for all strains tested. For the AE, MBC/MIC ratio was equal to 2 for all strains studied except *P. aeruginosa*. It appears that the AE has, also, a bactericidal effect.

Table 6. Antimicrobial parameters of *L. angustifolia* extracts and their interpretation

Strains	Essential oil				Aqueous extract			
	MIC	MBC	MBC/MIC	Interpret	MIC	MBC	MBC/MIC	Interpret
E. coli	8%	8%	1	Bd	100	200	2	Bd
S. aureus	4%	4%	1	Bd	100	200	2	Bd
P. aeruginosa	8%	4%	2	Bd	200	>200	--	--
E. faecalis	4%	16%	0.25	Bd	100	200	2	Bd

Interpret: Interpretation; Bd: bactericidal; --: not determined.

Antifungal activity of L. angustifolia

Results from inhibition rate of *F. oxysporum* as a function of concentrations of extracts were presented in Figure 1. It can be noted that AE was less effective on the target fungal strain compared to EO. In addition, both 1/100 and 1/250 (v/v) concentrations of EO resulted in complete inhibition of the fungus. In contrast, no concentration of AE resulted in complete inhibition of the strain studied. Analysis of the variance relative to percentage inhibition showed a non-significant effect between the two extracts studied (ddl= 1; F= 1.268; P= 0.269).

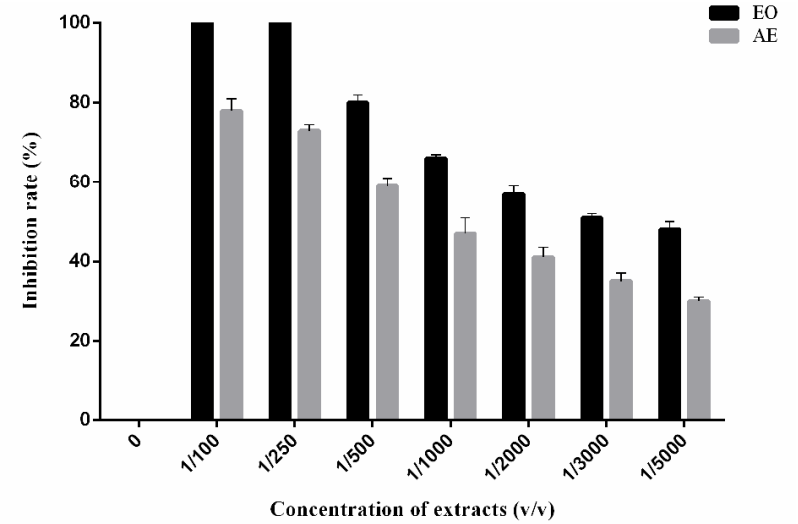

Figure 1. Inhibition rate of *F. oxysporum* against the different concentrations of *L. angustifolia* extracts

Evaluation of antioxidant activity of L. angustifolia

DPPH method

The IC_{50} recorded for butylated hydroxytoluene (BHT) and ascorbic acid (AA) used as reference molecules, were lower than that of the extracts studied (Table 7). Thus, the EO can reduce the stable free radical DPPH with an IC_{50} of 1.6 mg/mL showing an antioxidant activity greater than AE (1.86 mg/mL). The statistical treatment of the results allowed us to reveal a highly significant effect between the different extracts studied (ddl = 3. F= 207.801; P≤ 0.001).

Table 7. Antioxidant activities (expressed as IC_{50} in mg/mL) of the reference antioxidant and tested extracts of *L. angustifolia*

Extract	IC_{50} (mg/mL)
Butylated hydroxytoluene	0.24 ±0.001
Ascorbic acid	1.35±0.02
Essential oil	1.6 ±0.34
Aqueous extract	1.86 ± 0.23

Total antioxidant capacity method

Results of total antioxidant capacity showed a variability according to the nature of extract. At the concentration 4 mg/mL, the EO and the AE have higher antioxidant concentration, 819.6 ± 0.09 mg EAA/g and 339.2 ± 0.02 mg EAA/g respectively. In contrast, at the 0.125 mg/mL concentration, EO and AE record lower antioxidant concentrations, 125.20 ± 0.30 mg EAA/g and 75.06 ± 0.70 mg EAA/g respectively (Figure 2).

Statistical analysis showed a significant difference between the two extracts studied (ddl = 1; F = 7,711; P = 0,01).

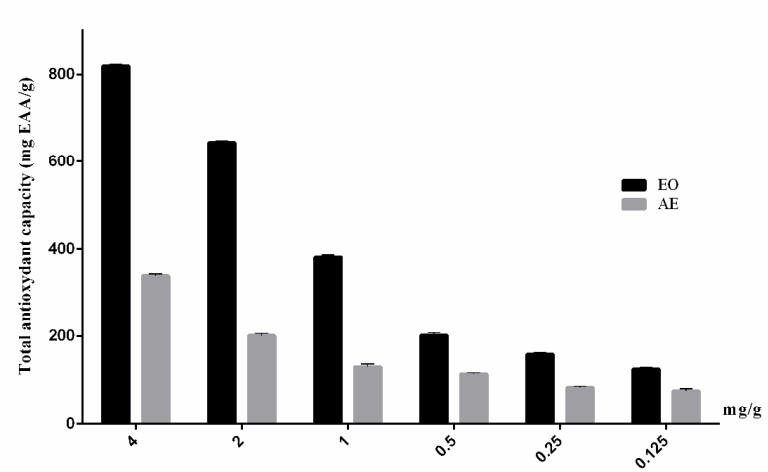

Figure 2. Total antioxidant capacity of the two tested extracts of *L. angustifolia*

Discussion

The analyses carried out in the present study enabled us to show that the yields of *L. angustofolia* extracts were 2.13 % and 21.68 % for the EO and the AE respectively. The EO yield obtained in our study was more important than that achieved by Elharas *et al.* (2013) where they reported a yield of 1.5 % from *L. angustifolia* harvested from Ifrane region, Morocco. Verma *et al.* (2010) indicate that aerial part of Indian *L. angustifolia* gives EO yield equivalent to 2.34 %. These results agreed with our experiment. Besides, the EO yield found by Benyagoub *et al.* (2015) was 4.12% obtained from Algerian *L. angustifolia*. The difference observed in the results may be due to a variety of conditions, including environment, genotype, and geographical origin of plant (Smallfield, 2001). In addition, results obtained in our study and that of Benyagoub *et al.* (2015) agree on the yields of AE. This last, found a yield equal to 24.07%.

The quantification of phenolic content in AE revealed the presence of polyphenols, flavonoids and condensed tannins. In comparison with similar species, Bachiri *et al.* (2016) showed that the levels of secondary metabolites, including polyphenols, flavonoids and tannins, were more important in *L. dentata* than in *L. stoechas*, and *L. angustifolia*. So, it is clear that, quantitatively, there is a difference between *L. angustifolia* ecotypes in terms of their phenolic contents which could be related to environmental factors such as drought, soil and diseases (Ebrahimi *et al.*, 2008; Liao *et al.*, 2021). Similarly, harvest period, stage of development and extraction method can also influence phenolic contents (Lee *et al.*, 2003). Benabdelkader (2012) cites a study realised by García-Vallejo (2009) showed a difference in phenolic content between certain species of lavender from different regions of Spain.

The analysis of EO by Gas Chromatography identified 21 compounds. The major components of this oil were: Linalool (29.95%), Linalyl acetate (18.86%), ρ-cymene (14.68%), and α-Campholenal (10.26%). Results were different from those obtained by Da Porto An et al. (2009) who examined the chemical

composition of *L. angustifolia* EO and they found 65 constituents with a predominance of Linalool (35.96-36.51%) and Linalyl acetate (21.74-14.42%). Another research done by Evandri *et al.* (2005) identified 14 monoterpene compounds in *L. angustifolia* EO. The major compounds were: Linalyl acetate (41.1%) and Linalool (32.7%). Thus, Reza Fakhari *et al.* (2005) found that Linalool (32.8%), Linalyl acetate (17.6%), lavandulyl acetate (15.9%), α-terpineol (6.7%), and geranyl acetate (5.0%) were predominant in *L. angustifolia* EO. Of the same, Rapper et al. (2016) established the chemical profile for *L. angustifolia* EO with major constituents, Linalyl acetate (36.7%), Linalool (31.4%), and terpinene-4-ol (14.9%). The difference in chemical composition of *L. angustifolia* EO can probably due to various conditions including the environment, genotype, geographical origin, period of harvest, location, temperature, drying time, parasites, and extraction method (Svoboda *et al.*, 1999).

The antibacterial activity showed that EO was active against the four target strains. These results agreed with Benyagoub *et al.* (2015) showed that *L. angustifolia* EO had an activity against all bacterial strains tested (*E. coli*, *S. aureus* and *P. aeruginosa*). Also, Cavanagh and Wilkinson (2002) had shown that lavender EO had an antibacterial action against *S. aureus* and *E. coli*.

The functional group structures of EO constituents could play an important role in determining the antibacterial activity of EO (Halle *et al.*, 2005; Danila *et al.*, 2021). This activity could be attributed to its chemical composition rich in terpenes such as linalool and linalyl acetate (Belmont, 2013; Yuan *et al.*, 2019).

Other researchers, including Haraguchi *et al.* (1998), Harborne *et al.* (2000) and Tim *et al.* (2005) reported that the presence of flavonoids contributes to antibacterial activity. It appears that this activity against Gram-positive bacteria was more important compared to Gram-negative bacteria, this may be due to the difference in the structure of their outer wall, as well as the membrane of Gram-negative bacteria richer in lipo-polysaccharides and protein that makes them more hydrophilic and prevents terpenes from adhering to these structures (Bosnić *et al.*, 2006; Marzouk *et al.*, 2006).

Besides, growth inhibition of *F. oxysporum* relative to control increases with concentrations of extracts. Do Amaral *et al.* (2000) and Castillejos et al. (1998) showed that the factor affecting the intensity of the antifungal action of an EO was the applied dose. This agreed with our results. In comparison with other fungus, Pepeljnjak *et al.* (1999) highlight the difference in sensitivity of organism test to lavender EO. Thus, they announce that the *F. oxysporum* was the most resistant among 6 species of *Penicillium*, 5 species of *Aspergillus* and one of *Rhisopus*. Those authors reveal a fungicidal activity on all the germs tested. In contrast, Laib (2010) reported that *L. angustifolia* EO reveal a negative inhibition rate against *F. oxysporum*, as if the EO stimulated the growth of the strain. Those results disagree with the present experimentation.

For the antioxidant activity, it seems that this one was related to the presence of phenolic contents. The main role of this compounds as free radical reducers was highlighted in several reports. The camphor present with 6.02% in *L. angustifolia* EO had a strong antioxidant activity (Svoboda *et al.*, 1999; Villano *et al.*, 2007; Kivrak, 2018). Besides, it can be noted that minority compounds present in EO can interact in a synergistic or antagonistic way to create an efficient system against free radicals. The presence of carvacrol even at low concentration in *L. angustifolia* EO (0.9%) may explain DPPH radical scavenging activity (Sing *et al.*, 2006). Similarly, Hui *et al.* (2010) analysed the antioxidant activity of lavender EO for inhibiting the peroxidation of linoleic acid. They found that the lavender EO had stronger antioxidant activity than vitamin E against lipid peroxidation.

Conclusions

Phytochemical analysis of *L. angustifolia* AE showed the presence of total phenolic contents, flavonoids and condensed tannins, and the analysis by Gas Chromatography of EO showed the presence of 21 majority and minority molecules. Also, the study of the antibacterial activity of *L. angustifolia* enabled us to obtain interesting results. Indeed, EO and AE were active against the most target strains. In addition, the two extracts,

EO and AE, were evaluated for their antifungal activity against *Fusarium axysporium* ssp*. albedinis*. EO showed significant activity on the filamentous strain tested. The AE proved less effective on this target fungal strain.

The evaluation of the antioxidant activity of *L. angustifolia* carried out by two techniques (DPPH and Total Antioxidant Capacity) showed a high antioxidant activity both for EO and AE. These eminent results showed that the use of *L. angustifolia* L. as an anti-infective in traditional environments is justified and that it should be studied more widely in order to explore its potential. Thus, it appears that this plant could be used as a means to retard or prevent the oxidation of biological substrates.

It would be important to extend the range of antimicrobial tests as well as the isolation, characterization, and identification of active compounds in *L. angustifolia* extracts. Also, research the biological activities of the same plant harvested in different regions in order to analyse the environment impact on the chemical composition of *L. angustifolia*.

Authors' Contributions

Data curation: CS, CR, GE, SB; Methodology: CS, CR; Supervision: HS, LG, AL, AF; Writing - original draft: CS; Writing - review and editing: CS.

All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

Acknowledgements

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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