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REVIEW ON DIFFERENT APPLICATIONS OF *Lavandula* spp. AS A SOURCE OF BIOACTIVE COMPOUNDS

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Abstract

Lavandula spp., commonly known as lavender, is an aromatic and medicinal plant that belongs to the Lamiaceae family and includes 47 known species of flowering plants of which we mention Lavandula angustifolia, Lavandula stoechas, Lavandula pedunculata, Lavandula dentata, Lavandula multifida, Lavandula latifolia, Lavandula viridis, Lavandula lanata, etc., many of them being hybrids or varieties with important economic value for the pharmaceutical, cosmetic, perfumery, food and agricultural industries. This paper reviews recent literature regarding the characteristics and properties of Lavandula spp., providing a comprehensive view about the use of lavender essential oils and plant extracts in various industrial fields. Variability is discussed by species, geographic area, plant material and extraction methods.

Key words*: biologic compounds, Lavandula spp., various applications.*

INTRODUCTION

The genus *Lavandula* comprises 39 species and numerous hybrids and cultivars (Benabdelkader et al., 2011), growing all over the world: Europe, North Africa, South-West Asia, Arabian Peninsula, India, North and South America (Lis-Balchin, 2012; Messaoud, 2012). Many researches have described the chemical composition and the main components of lavender oils, among which is counted monoterpenoids (linalool, linalyl acetate, 1,8-cineole, β-ocimene, terpinen-4-ol and camphor), sesquiterpenoids (β-caryophyllene) and other terpenoid compounds (Bikmoradi et al., 2017). It has been shown that lavender essential oil (EO) has an effect on the central nervous system (sedative, anticonvulsant, analgesic), and as well has antioxidant, antimicrobial, anti-inflammatory, spasmolytic and carminative activites (Bakkali et al., 2008; Hassiotis et al., 2010). *Lavandula* species, due to their high oil content, are used both as aromatic plants and for medicinal purposes. It represents an important source of raw material for the pharmaceutical, food, perfumery and cosmetic industries, but also for aromatherapy (Plotto & Roberts, 2001; Cavanach et al, 2002; Hyldgaard et al., 2012; Gutierrez, 2008; Adaszynska et al., 2013; Nieto, 2017; Sarkic & Stappen, 2018). Recently, certain compounds obtained from *Lavandula* spp. have been used in ceramics, in paint coatings and in porcelain (Yegorova, 2011).

The literature, as has been specified in this review, shows that the essential oils obtained from *Lavandula* spp. are promising in terms of their biological activity (Adorjan, 2010). They can be the subject of a technological transfer to the pharmaceutical, cosmetic and food industry in order to obtain innovative products, but their practical relevance must be evaluated through *in vitro* tests (Zuzarte et al., 2012).

The main uses of *Lavandula* in a variety of perfumes, soaps, creams are based on scent. *L. angustifolia* is preferred for perfumery, followed by *L. x intermedia* hybrid, which contains linalool and linalyl acetate as the main components. *L. latifolia* can be used in some food and household cleaning products, as well as in medicine (Hart & Lis-Balchin, 2002). Species rich in camphor are mainly used in aromatherapy and phytotherapy (Herraiz-Peñalver et al., 2013). The development of the lavender crops worldwide led to the definition of the international standards to assess the quality of the EOs (ISO 3515:2002/Cor 1:2004; NF ISO 3515:2004 (T75-301)).

The main purpose of this paper is to provide a systematic view on the lavender essential oil content, its chemical composition and its main uses.

Therefore, this paper is based on recently published articles related to lavender essential oil composition in bioactive compounds and its potential utilization in various industrial fields.

Essential Oil Composition

Currently, in specialized literature there is a lot of research related to essential oil compositions (Cavanagh & Wilkinson, 2005; Bombarda et al., 2008; Giray et al., 2008; Baydar & Kineci, 2009; Danh et al., 2013; Binello et al., 2014; Aprotosoaie et al., 2017; Dris et al., 2017; Tardugno et al., 2019; Detar et al., 2020; Giuliani et al., 2023). All these articles point to the fact that the composition of lavender essential oil is influenced by origin, genotype (Munoz-Bertomeu et al., 2007; Stanev, 2010), the stage of development (Lacusik et al., 2014), agronomic factors (Renaud et al., 2001; Angioni et al., 2006; Pinto et al., 2007; Erbaş & Baydar, 2008, Kara & Baydar, 2013; Camen et al., 2016; Garcia-Caparros et al., 2019; Lyczko et al., 2019; Fascella et al., 2020; Pecanha et al., 2021), parts of plant (Geisel et al., 2004; Lakusic et al., 2014) extraction method, storage and processing of biological material (Chemat et al., 2006; Karapandzova et al., 2014; Babu et al., 2016; Duskova et al., 2016; Salata et al., 2020;). Some authors have shown that there are no significant differences regarding the composition of the oil extracted by various methods. Microwave irradiation greatly accelerated the extraction process but without causing a change in composition. The essential oil contains more than a hundred components, of which the main are linalool (from 9% to 69%) and linalyl acetate (from 1.2% to 59%). The quality of this oil is given by the high content of linalool and linalyl acetate, but also by their proportions (Beale et al., 2017).

In the current literature, there is not a common point of view regarding the correlation between the harvest period and the composition of lavender oil. Some of the differences are visible between the genotypes. If in some situations the highest ratio of linalool was observed in the middle of the flowering period, and the highest percentage of linalyl acetate was detected at the end of flowering, in others cases increased amounts of linalool were recorded from full flowering to the end of the flowering phenophase while the amount of linalyl acetate decreased (Baydar & Kineci, 2009; Cantor et al., 2018; Detar et al., 2021). Other authors showed that linalool, terpinen-4-ol, 1,8-cineole, limonene recorded the highest concentration when the flowers were in buds.

The main constituents of lavender flower are representatives of the terpene compounds (oxygenated monoterpenes, 50-90%), followed by sesquiterpenes (7.5-15.0%) and triterpenoids (Bakkali et al., 2008; Lesage-Meessen et al., 2015; Chrysargyris et al., 2016). The diversity of compounds is highly variable depending on the species. Therefore, regarding oxygennated monoterpenes content, for *L. angustifolia* was reported 36-93%, for *L. x intermedia* 68-93%, for *L. stoechas* 46-93% and for *L. latifolia* 85-94%. High values are also specific for *L. pedunculata, L. luisieri* and *L. viridis*. The richest species in sesquiterpenes are *L. angustifolia, L. stoechas* and *L. luisieri* (over 20%) (Aprotosoaie et al., 2017).

The most common monoterpenoids of lavender EOs reported from flowers are linalool, terpinen-4-ol, a-terpineol, borneol, lavandulol, linalyl acetate, lavandulyl acetate, geranyl acetate, geranyl propionate, camphor, fenchone, thujone and 1,8- cineole. The monoterpenes reported in lavender EOs are limonene, cis-b-Ocimene, trans-b-Ocimene and the sesquiterpenes are b-caryophyllene, b-farnesene, caryophyllene oxide and viridiflorol (Chrysargyris et al., 2016).

Table 1. Composition of lavender essential oils

Origin	Reference	The main compounds of lavender essential oil (%)													
		Linalool	Linalyl acetate	β-Ocimene	1,8-Cineole	Camphor	Limonene	Terpinen-4-ol Gammaterpinene	Borneol	lavandulol acetate	Geranyl acetate/ Bornil acetil	b-caryophyllene	β-farnesene	α-pinene/y cadidene	Eucaliptol/ camphene/ others
Romania	Oroian et al., 2019, LA	18.46-39.5	25.64-29.86	1.63-14.39	0.16-0.74	0.21-0.31	ND	ND	1.72	ND	ND	ND	ND	ND	ND
Romania	Gonceariuc et al., 2018, LA	24.15-50.84	27.29-44.40	0.2-1,8	0.31-1.61	0.2-0.35	0.16-0.92	1.11 – 9.21	0.75-2.2	0 – 2.22	0.64-1.64	1.41-2.40	ND	ND	ND
India	Raina et Negi, 2012, LA	23.6	35.8	1.5	1.8	1.4	0.6	ND	1.4	4.8	ND	1.8	ND	ND	ND
Hungary	Detar et al., 2021, LA	5.1-62.7	2.6-34.9	0.1-8.2	0.2-32.8	0.2-19	0.4-4.0	0.6-23.9	0.6-11.9	0.2-2.17	0.1-1.3	0.1-3.7	ND	ND	ND
France	Beale et al., 2017, LA	9.3-68.8	1.2-59.4	0.2-18.1	0-3.4	0-0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bulgaria	Ognyanov, 1984, LA	30.1-33.7	35.2-37.6	6.8-7.7	2.1-3.0	< 0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bulgaria	Todorova et al., 2023, LA	23.13-35.52	20.79-39.91	0.29-7.19	0.13-8.29	-	0.33-1.31	-	-	4.21 0.41	-	6.09 1.96	Tr-3.99	-	-
Syria	Al-Wassouf et al., 2018, LA	27.3-34.7	19.7-22.4	1.9-2.9	0.2-0.5	0.2-0.3	ND	ND	ND	ND	ND	ND	ND	ND	ND
Serbia	Lakusik et al., 2014, LA	28-37	00.3-3.3	1.1-2.8	20.5-43	8.9-14.2	-	0.6-4.7	10-24.7	0.2-0.3	0.1-0.9	ND	ND	ND	ND
Poland	Walasek-Janusz et al., 2022, LA	15.1-21.77	ND	16.87-34.22	ND	0.56	1.19-2.77	1.79-3.49	1.92-2.45	5.8-8.25	1.9-2.17	0.5-1.47	ND	ND	ND
Poland	Łyczko et al., 2019, LA leaves (dried)	ND	2.21±0.73	ND	ND	2.09 ± 0.29	3.42 ± 1.16	4.09 ± 0.67	4.66 ± 0.69	ND	5.57±0.82	6.11 ± 1.48	ND	10.53± 1.51	7.28 ± 1.06
Italy	Evandri et al., 2005, LA	32.7	43.1	ND	0.8	0.5	0.3	3.1	0.8	ND	ND	4.9	0.8	ND	ND
Italy	Alteriis et al., 2022, LA	39.31	48.45	ND	1.2	0.11	ND	1.4	ND	2.17	ND	2.01	ND	ND	ND
Croatia	Blazekovic et al., 2018, LA	3.97	11.56	0.6	2.94	0.34	0.47	4.7	ND	3.67	1.09	0.29	ND	ND	ND
France	Lawrence, 1993, LA	9.3–68.8	1.2–59.4	0.2–18.1	0–3.4	0.5	ND	0.1–13.5	ND	21.6	ND	ND	ND	ND	ND
China	Xiaotiana et al., 2020, LA	24.30	28.89	ND	ND	0.39	ND	4.4	2.6	ND	0.89	7.89	ND	ND	ND
Algeria	Djenane et al., 2012, LA	22.3	21.8	9.3	1.31	ND	1.18	5.19	2.1	4.99	ND	4.83	ND	ND	ND
Greece	Adam et al., 1998, LA	20.18	18.60	ND	13.1	ND	ND	ND	ND	16.01	ND	ND	ND	ND	ND
India	Fakhari et al., 2006, LA	35.3	13.42	ND	ND	ND	ND	ND	ND	10.90	ND	ND	ND	ND	ND
Cyprus	Chrysargyris et al., 2016, LA	0.17-0.24	ND	ND	58.67-62.28	7.43-11.26	ND	0.6-0.74	9.1-12.34	ND	ND	ND	ND	ND	ND
USA	Wang et al., 2021, LA	29-33	20-49.44	1.15-2.57	ND	0.2-04	ND	ND	2.8-5.6	3.28-4.65	0.4-0.8	3.5-4.84	ND	ND	ND

Table 1. Composition of lavender essential oils (continuation)

Origin	Reference	The main compounds of lavender essential oil (%)													
		Linalool	**Linalyl acetate**	**β-Ocimene**	**1,8-Cineole**	**Camphor**	**Limonene**	**Terpinen-4-ol Gammaterpinene**	**Borneol**	**lavandulol acetate**	**Geranyl acetate/ Bornil acetil**	**b-caryophyllene**	**β-farnesene**	**α-pinene/y cadidene**	**Eucaliptol/ camphene/ others**
Romania	Marincaş & Feher, 2018, *Lavandula x intermedia* (LI)	21.9 ± 5.27	33.8±8.34	5.62±3.1	ND	0.83±1.72	1.84 ± 1.87	3.13 ± 2.06	2.82 ± 1.63	33.8 ± 8.34	ND	3.67 ± 1.27	ND	ND	ND
Spain	Marin et al., 2016 LO	34.34	34.19	5.05	1.71	0.39	ND	2.43	ND	4.4	0.41	3.83	3.08	ND	ND
Argentina	Martucci et al., 2015, LO	53.5	4.2	-	6.8	8.4	-	7.6	4.7	-	-	-			
Italy	Garzoli et al., 2019, LI	41.6	23	ND	19.8	4.4	3.5	4.8	2.8	3.2	ND	ND	ND	8.7	ND
Poland	Walasek-Janusz et al., 2022, LI	25.53-29,56	ND	18.56-21.05	ND	ND	9.57	3.52-18.08	4.58	3.5-6.9	1.24-3.36	0.75-1.47	ND	ND	ND
Croatia	Blazekovic et al., 2018 LI	57.1	9.83	0.35	8.44	0.12	3.97	3.33	ND	0.2	1.12	0.17	ND	ND	ND
Portugal	Costa et al., 2013b, LV	0.93/L oxid=7/93	ND	ND	7.81	22.4	ND	3.55	2.7	ND	ND	ND	ND	ND	ND
Spain	Méndez-Tovar et al., 2016, LL	30.34 ± 7.69	0.62	0.28	41.96±5.48%	9.27±2.46	ND	0.09	1.67	ND	ND	0.44	ND	ND	ND
India	Al-Ansari et al., 2021, LL	9.1	ND	ND	10.2	13.8	ND	9.1/26.8	ND	9.3	ND	ND	ND	ND	2.32
Morocco	Ez-zoubi et al., 2022, LS	0.74	ND	ND	ND	43.97	0.32	0.22	2.92/1.29	ND	ND	ND	30.39	ND	ND
Brazil	Cossetin et al., 2021 LD	ND	ND	ND	50.73	15.18	ND	ND	ND	ND	ND	ND	17.11	ND	ND
India	Hanamanthagouda et al., 2010, LB	ND	3.37	ND	ND	7.09	ND	ND	ND	ND	ND	3.68	ND	ND	//transcarveol (18.93%), pulegone (8.45%),menthol (5.89%). Pipertone 4.65bicyclogermacrene3.02

[1]LA = *Lavandula angustifolia;* [2]LL = *Lavandula latifolia;* [3]LO = *Lavandula officinalis;* [4]LI = *Lavandula intermedia;*
[5]LV = *Lavandula viridis*; [6]LS = *Lavandula stoechas*; [7] LD = *Lavandula dentata*; [8]LB = *Lavandula bipinnata;*
[9]ND = not detectable.

In the lavender oil obtained from leaves there are predominant the following bioactive compounds: 1,8-cineol (42.17%), p-cymen-8-ol (14.05%), borneol (6,32%), o-cymene (4.38%), bornyl acetate, p-cimene (14.06%), camphor (2.32%) (Giuliani et al., 2023). Perino-Issartier et al. (2013) reported that French lavandin, Grosso cultivar, contains high concentrations of linalool (45.51-47.51%) and linalyl acetate (45.1-48.2%). In *L. stoechas*, the concentrations of linalool and linalyl acetate are very low or absent (Gyrai et al., 2008). 1,8-cineole and camphor are predominant in the essential oils from *L. angustifolia* leaves and stems. Lavandin EOs have higher 1,8-cineole (1.8–47.9%) and camphor contents (2.2–32.7%) (Flores et al., 2014). In *L. latifolia* from Spain, Garcia-Vallejo (1992) reported the hight content in 1,8-Cineole (8.8-71.5%) and camphor in *L. pedunculata* (4.3-84.4%). Fenchone was detected as major compound in *L. stoechas* EOs (3.06-75.50%) (Benabdelkader et al., 2011). Borneol and Terpinen-4-ol and a-Terpineol are abundant in essential oils of *L. angustifolia* (2-14.01% and 2-9.17%). The presence of 4-terpineol (30%) was detected in samples from China, Spain and Italy (Chen et al., 2020). The chemical composition for *L. angustifolia* EOs is under regulation by ISO 3515:2002, respectively ISO 8902:2009 for *Lavandula x intermedia* Grosso, and ISO 4719:2012 for *L. latifolia.* Table 1 presents the main compounds of lavender EOs depending on the country of origin and the considered species.

Utilization of Lavandula spp. EOs and extracts

The *Lavandula* genus is known for its versatility regarding the uses of EOs in different products. Its use continues to be popular in aromatherapy, pharmaceuticals and medical applications (Pistelli et al., 2017). It is known that only the oil obtained from *Lavandula* flowers is used in medicine (European Pharmacopoeia, 2008), but latest research has shown that oil from lavender leaves has also an important role due to the high percentage of camphor (Lyczko et al., 2019). Also, *Lavandula angustifolia*, *L. latifolia*, *L. intermedia* and *L. stoechas* oil and aqueous extracts have been used in perfumery, cosmetics, food manufacturing and in agricultural application (Upson & Andrews, 2004). The scent of lavender is used in home and pet care products and gives a special taste to drinks, sweets, jams, puddings, chewing gum, chocolate, etc. The most common *Lavandula* spp. utilizations are listed in Table 2.

Table 2. *Lavandula* spp. EOs and extracts utilizations

Species	Utilisation	References
Lavandula angustifolia	Therapeutic potential	Bertram, 1995; Buyukokuroglu et al., 2003; Hajhashemi et al., 2003; Woronuk et al., 2011; Raut & Karuppayil, 2014; Koziol et al., 2015; Kivrak, 2018; Malcolm & Tallian, 2018; Bialon et al., 2019; Donatello et al., 2020; Zeinab et al., 2020; Detar et al., 2021; Doha et al., 2021; Firoozeei et al., 2021; Villalpando et al., 2022; Saeed et al., 2023.
	Cosmetic products	Koniger, 1997; Fakhari et al., 2005; Kunicka-Styczynska, 2009; Adaszynska et al., 2013; Kunicka-Styczynska et al., 2015; Saeed et al., 2023.
	Food manufacturing	Fenaroli, 1998; Fakhari et al., 2005; Adaszynska et al., 2013; Fascella et al., 2020.
	Amendment of soils	Yohalem & Passey, 2011.
	Insecticidal effect	Carson & Riley, 1995; Sertkaya et al., 2010; Khosravi et al., 2013; Yazdani et al., 2013; Julio et al., 2014; El Abdali et al., 2022; Ez-zoubi et al., 2022.
	Veterinary products	Wren, 1988; Ercan & Esma, 2019.
	Repellent	Warren et al., 1997.
	Allelopathy	Sidorenko et al., 1995.
	Acaricidal effect	Perrucci et al., 1996; Kaya, 2010.
	Aromatherapy	Lis-Balchin & Hart, 1999; Evandri et al., 2005; Umezu et al., 2006; Michalina et al., 2019; Donatello et al., 2020.
Lavandula coronopifolia	Therapeutic potential	Said et al., 2015; Hasanin et al., 2020; Naseef et al., 2022.
	Phytoremediation of Soils	Shafagha et al., 2012.
	Food manufacturing	Preedy, 2016.
	Veterinary use	Ferguson,et al, 2013.
Lavandula dentata	Therapeutic potential	El Abdali,2022; Bouyahya et al., 2023.
Lavandula stoechas L.	Pharmaceutical and perfume industries	Repici, 2019.
	Therapeutic potential	Bouyahya et al., 2017; Chograni et al., 2021; Rasheed et al., 2023.
	Cosmetic use	Bouyahya et al., 2017.

Table 2. *Lavandula* spp. EOs and extracts utilizations (continuation)

Species	UTILISATION	References
Lavandula x allardii	Fragrance, food, cosmetic and pharmaceutical industries	Chasiotis et al., 2021.
Lavandula latifolia	Food industry	Fenaroli, 1998; Mendez-Tovar et al., 2016.
	Medicinal purposes	Rodrigues et al., 2012; Herraiz-Peñalver et al., 2013; Gayoso et al., 2018; Al-Ansari et al., 2021.
	Insecticidal use	Al-Ansari et al., 2021.
Lavandula officinalis	Medicinal purposes	Meftahizade et al., 2011; Imene, 2012; Et-Touys et al., 2016; Kivrak, 2018.
Lavandula x intermedia	Food	Fenaroli, 1998.
	Anaesthetic	Krasteva et al., 2021; Yigit et al., 2022.
Lavandula luisieri	Antifeedant	Gonzalez-Coloma et al., 2011.
Lavandula multifida	Therapeutic potential	Benbelaid, 2012.

Lavandula* spp. *EOs and extracts properties

Lavandula spp. EOs have demonstrated biological activity in the field of antioxidant, antimicrobial and anti-inflammatory properties. The antioxidant activity of lavender EOs has been evaluated in many studies (Table 3). There are different reports of this activity as a result of the different tests used for their evaluation - the DPPH analysis, respectively the ABTS assays (the relative ability of antioxidants to scavenge the ABTS - 2,2'-azino-bis (3-ethylbenzothiazoline- 6-sulfonic acid) generated in aqueous phase) (Ionita, 2021), and ORAC assays (The Oxygen Radical Absorbance Capacity) (Gupta., 2015; Kasote et al., 2019).

Regarding the antioxidant activity, significant differences have been demonstrated between different authors due to the genotypic variability (Mendez-Tovar et al., 2015), the phenophase of the plant, extraction method (Karabagias et al., 2019) as well as the agro-pedoclimatic conditions and the conditioning of the biological material (Baptista, 2015). The main biologically active compounds of lavender spp. are components of essential oil, phenolic compounds, triterpenes and sterols. *Lamiaceae* Family is a rich source of phenolic acids, especially rosmarinic acid (Zgorka & Głowniak, 2001; Turgut et al., 2016; Costa et al., 2013a). A lower content of polyphenols was reported for *L. angustifolia* than in the case of other plants from the same family (50.6 mg GAE/g compared to 67.8 mg GAE/g in *Origanum vulgare*) (Spiridon et al., 2011). Dobros et al. (2023) presented in an exhaustive manner the most common phenolic acids in *Lavandula* spp.

Table 3. Antioxidant capacity of *Lavandula* spp. EOs and extracts

Species	Extract type/part of plant/extraction method	Antioxidant activity	References
angustifolia Mill.	Aqueous-ethanol extraction/flowers DPPH [µg/mL] Fe2+ chelation assay [µg/mL]	49.93+-0.75 -110.36+-1.40 (according to ssp)	Robu et al., 2012.
	Infusion/ aerial plant/ABTS [mM]	0.72 ± 0.07	Ivanova et al., 2005.
	Inflorescent/DPPH	27.67± 0.56	Blazekovic et al., 2018.
	Shaking/leaves/DPPH [µmol TEAC/g DW]	9.00 ± 3.00, 14.17 ± 9.09	Ahn et al., 2020.
	Shaking/herb/ ABTS [µmol/100 g DW]	22.00 ± 0.00 20.19 ± 2.55	Blazekovic et al., 2010.
	Ultrasonic assisted extraction/ flowers * leaves inflorescence stalks/ DPPH * [µg/mL] TBARS * [µg/mL] Fe2+ chelation assay * reducing power	11.37 ± 0.69 89.36 ± 5.00 319.21 ± 21.96	Blazekovic et al., 2010.
	Ultrasonic assisted extraction/herb/ ABTS [mmol/100 g DW]	10	Dvorackova et al., 2014.
	Pulsed ultrasound-assisted extraction/ flower residues after the distillation of essential oil/DPPH [mg TE/g of dry waste]	107.29 ± 0.05	Turrini et al., 2021.
	Supercritical fluid extraction (SFE)/flowers/ DPPH [%]	50.55 ± 0.7 78.83 ± 1.3	Tyskiewicz et al., 2019.
	flower	95+-3.98 mg AA	Zgorka & Głowniak, 2001.
	Aerial parts/ DPPH%assaySC50(μgmL^{-1})	97.61±0.15-105.08±0.08	Kıvrak, 2018.
	SFE/flower/ DPPH% HD Solvent extraction	63% 48% 12%	Danh et al., 2013.
	Flower/DPPH (mg TE g^{-1} FW) ABTS (mg TE g^{-1} FW TRP (mg AAE g^{-1} FW) FRAP (mg Fe g^{-1} FW)	3.20±0.4 2.54±0.2 0.11±0.02 1.19±0.4	Nikolic et al., 2019.

Table 3. Antioxidant capacity of *Lavandula* spp. EOs and extracts (continuation)

	Aerial plant/(mg g^{-1}) Aerial plant AMF inoculation	38.66±1.3 73.3±1.3	Golubkina et al., 2020.
	mg AA/g	953.98	Spiridon et al., 2011.
	Aerial part/CL-chemiluminescence DPPH/%	88.66 86.693	Bunghez et al., 2015
L. latifolia	Shaking/leaves/DPPH [µmol TEAC/g DW]	6.56 ± 1.13	Ahn et al., 2020
	Aerial parts/DPPH EC50 (mg/mL)	1.85 ± 0.05- 4.56 ± 0.15 (2009) 2.94 ± 0.09- 5.69 ± 0.35 (2010)	Mendez-Tovar et al., 2018
L. × intermedia	Inflorescences/DPPH(mg/mL)	21.58 ± 0.26	Blazekovic et al., 2018.
	Ultrasonic assisted extraction/flowers * leaves inflorescence stalks/DPPH * [µg/mL] TBARS * [µg/mL] Fe2+ chelation assay * reducing power *	17.17 ± 0.33 116.54 ± 9.96 397.71 ± 10.26	Blazekovic et al., 2010.
	Aerial parts/ DPPH assay SC50 (µgmL^{-1})	89.81±0.17 93.20±0.10	Kıvrak, 2018.
L. hybrida	Aqueous-ethanol extraction/ flowers DPPH [µg/mL] Fe2+ chelation assay [µg/mL]	73.53 ± 1.25	Robu et al., 2012.
L. pedunculata	Infusion/flowering stems/DPPH [µg/mL] TBARS [µg/mL] reducing power [µg/mL]	68 ± 0.5–191 ± 2; 14 ± 1–39.1 ± 0.1; 51 ± 1–167 ± 1	Lopes et al., 2018.
	Maceration/aerial parts/TEAC (w, w/e, e) [µmol TE/g extract] ORAC (w, w/e, e) [µmol TE/g extract] TBARS (w, w/e, e) [%] Fe2+ chelation assay (w, w/e, e) [%]	670.95 ± 4.24; 569 ± 1.99; 1530 ± 121; 96 ± 2	Costa et al., 2013.
L. viridis	Maceration/aerial plants/ORAC (w, w/e, e) [µmol TE/g extract], TEAC (w, w/e, e) [µmol TE/g extract]	1502.22 ±39.95 670.95 ± 4.24	Costa et al., 2013.
L. luisieri	Oil aerial parts/ DPPH, TBARS	moderate antioxidant capacity	Matos et al., 2009.
	Randall Extraction/herb/DPPH [µg/mL]	30.66 ± 1.9	Gimenez-Rota et al., 2019.
	Supercritical antisolvent fractionation/herb/ DPPH [µg/mL]	16.17 ± 0.7	Gimenez-Rota et al., 2019.
L. stoechas	Methanol extraction/flowers/ DPPH [mg/mL]	7.05	Karabagias et al., 2019.
	Aqueous extraction/flowers/ DPPH [mg/mL]	1,78	Karabagias et al., 2019.
	Infusion with stirring/ DPPH [%] Fe2+ chelation assay superoxide anion	45 ± 0.0 84 ± 0.0 78 ± 0.0	Gulcin et al., 2004.
	ORAC (µmol TE/mL EO) ABTS (µmol TE/mL EO) DPPH (µmol TE/mL EO)	1.42-2.22 160.9-175.3 0.5661-1.3	Carrasco et al., 2015.
L. officinalis	Oil commercial/FRAP/ TEAC $^{¥}$ (mmol/L Trolox)	0.14-0.24+-0.02	Marin, 2016.
L. spica	Oil commercial/ IC50 - mg/L	1828.25	Badr et al., 2021.
L. coronopifolia	Flower/DPPH [µg/mL]	17.8 ± 0.8	Abdelaziz et al., 2020.

Antimicrobial properties of lavender volatile oil

Recently, new non-toxic molecules with antimicrobial effect obtained from essential oils have been developed (Bakkali et al., 2008). This was necessary because the development of antibiotic resistance against MRSA (Methicillin-resistant *Staphylococcus aureus*) limited their effectiveness (Guo et al., 2020). The efficiency of different essential oils against bacteria and fungi, including the essential oil from *Lavandula* spp., have been compared in the literature by analysing the concentrations required to inhibit the growth of the target organisms. To compare the bioactivity of essential oils, most authors used standardized methods such as minimum growth inhibitory concentration (MIC), minimum lethal concentration (LD - lethal dose) minimum bactericidal concentration (MBC) or minimum fungicidal concentration (MFC), MIC50 and LD50 values (Stanlay & Deans, 2002; Lopez et al., 2005; Raut, 2014; Balouiri et al., 2016; Garzoli et al., 2019). The antimicrobial activity of essential oils can be minimized due to the volatility or decomposition of the compounds subjected to various extreme factors. The works of some authors have demonstrated the effectiveness of *Lavandula* spp. EOs against strains sensitive to drugs, as well as against strains resistant to them, regardless of their potential against biofilms that are tolerant to antibiotics (Galvao et al., 2012).

Regarding the antibacterial and antifungal activity of lavender essential oil, it depends on many factors that affect its composition, such as agricultural technology, harvesting, drying, the part of the plant that is used, the obtaining method for oil and the genetic variation (Walasek-Janusz et al., 2022).

The antibacterial and antifungal effects of *Lavandula* spp. oils are due to the properties of their many components (Jianu et al., 2013). Some authors state that linalool, linalyl acetate, eucalyptol, terpinen-4-ol, β-ocimene, limonene, α-pyrene lavandulyl acetate, borneol, camphor are responsible for antimicrobial properties (Orhan et al., 2011; Lesage-Meessen et al., 2015). Others, such as Shafagha et al. (2012), reported that antimicrobial activities of essential oils of *Lavandula* spp. are difficult to correlate to a specific compound due to their complexity and variability. *Lavandula* spp. EOs has been found to be active against many bacteria, predominantly against Gram-positive, but also against Gram-negative bacteria, including multidrug-resistant bacteria (Teixeira et al., 2013; Gismondi et al., 2021) and fungi (Bouzouita et al., 2005). Some work reports the antifungal activity of *Lavandula* EOs against yeast, dermatophyte and *Aspergillus* strains responsible for human infections and food contamination (Zuzarte et al., 2012). Many studies have demonstrated the effectiveness of lavender EOs against *Enterococcus faecalis*. Also, genus *Bacillus* has been shown to be susceptible to lavender volatile oil in a number of studies (Deans & Ritchie, 1987). Growth inhibition in Gram-positive bacteria was observed at lower concentrations than in Gram-negative bacteria, and yeasts showed significantly greater sensitivity to the *Lavandula* spp. EOs than Gram-positive and Gram-negative bacteria (Walasek-Janusz et al., 2022). Some authors appreciate that EOs can be used as food preservatives due to the phenolic compounds responsible for the antioxidant properties (Zeng & Wang, 2001). Although many studies have been conducted regarding the use of EOs as preservative agents, there are limitations regarding this use. The main limitations are based on the fact that EOs are strong flavorings and are not acceptable from a sensorial point of view for some foods. Also, the concentrations added to the products are reduced and are not sufficient from the point of view of the antimicrobial effect, which implies the combination with other antimicrobial agents (Marin, 2016).

EOs are used to control phytopathogenic microorganisms in the agricultural sector (Al Ansari et al., 2021). EOs extracted from *L. latifolia* and *L. stoechas* demonstrated effectiveness against *F. oxysporum, R. solani, A. nidulans*. EOs extracted from *Lavandula* showed a least activity against *Aspergillus flavus* (Angioni et al., 2006). *Lavandula angustifolia* EOs demonstrated antifungal activity against *T. mentagrophytes, A. nidulans,* whereas *L. stoechas* EOs was effective against *Sclerotinia sclerotiorum* and *Leptosphaeria maculans* (Angioni et al., 2006; Moon et al., 2007). *Lavandula dentata* EO has inhibitory activity against fungi, such as *C. albicans, P. notatum, A. niger*, and also against gram positive bacteria, like *E. faecalis, B. subtilis, S. aureus, Micrococcus* spp. and gram-negative bacteria, *P. aeruginosa, E. coli* (Hanamanthagouda et al., 2010). Stanojevic et al. (2011) has demonstrated inhibitory activity of lavander EOs against *Aspergillus niger, Candida albicans*, *Klebsiella pneumonia* and *Salmonella enteritidis*. Generally, the essential oil showed better antibacterial activity than antifungal activity (Table 4).

Table 4. Antimicrobial activity of *Lavandula* spp. EOs and extracts

Species/MIC	Microorganisms	Inhibitory zone	References
L. luisieri		MIC (μg/L)	Zuzarte et al., 2012
	C. albicans,	0.64-2.5	
	Cryptococcus neoformans,	0.64	
	Aspergillus strains	0.16-0.32	
L. spica		(mg/L)	Badr, 2021
Conc. 250, 500, 1000, 2000, and 3000 mg/L	*S. typhimurium,*	3000	
	S. aureus,	3150	
	A. flavus,	EC50 = 1145.13	
	A. niger	905.43 mg/L	
L. tenuisecta		MIC (μg/L)	Sayout et al., 2020
	Staphylococcus aureus,	6.25	
	Enterobacter aerogenes,	6.25	
	Pseudomonas aeruginosa,	16.66	
	Klebsiella pneumoniae,	12.5	
	Klebsiella oxytoca,	12.5	
	Acinetobacter baumannii,	12.5	
	Enterobacter cloacae	25	

Table 4. Antimicrobial activity of *Lavandula* spp. EOs and extracts (continuation)

Species/MIC	**Microorganisms**	**Inhibitory zone**	**References**
Lavandula multifidi Conc. 4 to 0.007 mg/mL	 *Enterococcus faecalis* ATCC, *Escherichia coli* ATCC, *Pseudomonas aeruginosa* ATCC 27853, *Klebsiella pneumoniae* ATCC 70603, *Staphylococcus aureus* ATCC 25923, *Candida albicans* ATCC 10231, *Listeria monocytogens* ATCC 19115, *Bacillus cereus* ATCC 11778, *Bacillus subtilis* ATCC 6633	µl/ml 0.2500 0.5000 10.00 0.5000 0.2500 0.0625 0.2500 0.0312 0.0312	Khadir et al., 2012
L. stoechas subsp. *luisieri*	 *Aspergillus niger,* *Candida albicans,* *Candida guillermondii,* *Cryptococcus neoformans,* *Rhodotorula rubra,* *Saccharomyces cerevisiae,* *Trichosporon cutaneum*	µg/mL) 15.5 >100 62.5 15.5 >100 31 31	Baptista et al., 2015
L. pedunculata	 *Aspergillus niger,* *Candida albicans,* *Candida guillermondii,* *Cryptococcus neoformans,* *Rhodotorula rubra,* *Saccharomyces cerevisiae,* *Trichosporon cutaneum*	MIC (µg/mL) >100 >100 62.5 15.5 62.5 >100 62.5	Baptista et al., 2015
L. bipinnata Conc. 0.5 to 2.0 µg/µl bacteria 2 to 4 µg/µl fungi	*E. coli* ATCC 25922, *P. aeruginosa* ATCC, *Sh. dysenterie,* *E. faecalis* ATCC, *S. aureus* ATCC, VRE ATCC 51299, *B. subtilis,* *Micrococcus,* *A. niger,* *P. notatum,* *C. albicans*	< 0.5 < 2 < 1 < 2 < 1 < 2 < 1 < 0.5 < 2 < 4 < 4	Hanamanthagouda et al., 2010
Lavandula officinalis 20-40 µL	 *Listeria innocua.*	MIC-mm 13.25-17.00	Marin, 2016
L. officinalis, stem and leaf, Conc. 30 µL	*B. subtilis,* *S. epidermidis,* *S. aureus,* *E. faecalis,* *K. pneumonia,* *P. aeruginosa,* *E. coli,* *A. niger,* *C. albicans,* *S. cerevisiae*	11.7-22.1 8.9-25.6 7.2-21.5 9.2-23.3 12.6-16.1 8.4-10.8 7.5-20.3 8.2-15.6 9.9-16.1 9.5-16.9	Shafagha et al., 2012
L. latifolia conc. 0.025 to 10%	 *A. flavus,* *A. nidulans,* *T. mentagrophytes,* *L. maculans,* *R. solani,* *F. oxysporum*	µg/mL 2.5 ± 0.225 >10 0.125 5 ± 0.065 2.5 >10	Al Ansari et al., 2021
Lavandula × intermedia Conc. 40, 20, and 2 µL	 *E. coli,* *A. bohemicus,* *P. fluorescens,* *B. cereus,* *K. marina*	MIC 20 µL <2 >40 20 20 20	Garzoli et al., 2019
L. angustifolia Conc. 20, 10, 5, 2.5, 1.25, 0.6, 0.3, 0.16, 0.08, and 0.04 mg/mL	 *Staphylococcus aureus* ATCC, *Staphylococcus epidermidis* ATCC 12228, *Enterococcus faecalis* ATCC 29212, *Micrococcus luteus* ATCC 10240, *Bacillus subtilis* ATCC 6633, *Bacillus cereus* ATCC 10876, *Salmonella typhimurium* ATCC 14028, *Proteus mirabilis* ATCC 12453, *Bordetella bronchiseptica* ATCC 4617, *Escherichia coli* ATCC 25922, *Pseudomonas aeruginosa* ATCC 27853, *Candida albicans,*	µg/mL 5-10 2.5-10 10 2.5 5 5 10 10 2 10 10 0…3-1.25	Walasek-Janusz et al., 2022

Table 4. Antimicrobial activity of *Lavandula* spp. EOs and extracts (continuation)

Species/MIC	Microorganisms	Inhibitory zone	References
	Candida auris, *Candida lusitaniae* ATCC 3449	1.25 1.25	
Lavandula angustifolia Mill. Conc. 0.39-12.480 µg/mL	*C. albicans.*	MIC µg/mL 512	Khoury et al., 2016
Lavandula viridis	*C. parapsilosis,* *C. tropicalis*	MIC µL/mL 1.25 1.25-2.5	Zuzarte et al.. 2011

CONCLUSIONS

The results obtained from the literature review of *Lavandula* EOs are promising in terms of obtaining natural products that have action against pathogenic fungi and bacteria. Overall, results of the current study suggest that *Lavandula* EOs are worth of further investigations for potential use in combination with antibiotic therapy in order to minimize the lowest effective dose of drugs and to minimize the resistant bacteria development. *Lavandula* EOs have a good potential for antioxidant activity, which is related to phenolic compounds, and can be used in preserving foods. Furthermore, it is necessary to evaluate the practical relevance for pharmaceutical, cosmetic and food industries.

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