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Essential oils of *Lavandula* genus: a systematic review of their chemistry

Ana Clara Aprotosoaie · Elvira Gille · Adriana Trifan · Vlad Simon Luca · Anca Miron

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Abstract *Lavandula* species are one of the most useful aromatic and medicinal plants with a great economic value for pharmaceutical, food and flavor industries, cosmetics, perfumery, and aromatherapy. The pleasant fragrance, physiological effects, and commercial significance are due to the their essential oils, with a highly variable composition dependent on the genetic, environmental and processing factors. This paper provides a systematic view on the chemistry of lavender essential oils especially considering the studies in the last 15 years. The review presents the characteristic chemical constituents and chemotypes of seventeen *Lavandula* species. The intra- and interspecific variability is primarily discussed dependent on the geographic area, onto-and morphogenetic factors, and extraction methods. In addition, biosynthesis of lavender terpenes is presented.

A. C. Aprotosoaie (✉) · A. Trifan · V. S. Luca ·
A. Miron
Department of Pharmacognosy, Faculty of Pharmacy,
University of Medicine and Pharmacy Grigore T. Popa
Iasi, Universitatii Str. No. 16, 700115 Iasi, Romania
e-mail: anaclara70@yahoo.com;
ana.aprotosoaie@umfiasi.ro

E. Gille
National Institute of Research & Development for
Biological Sciences Bucuresti/Biological Research
Centre, Alexandru cel Bun No. 6, 610004 Piatra Neamt,
Romania

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Introduction

The genus *Lavandula* comprises 39 species, numerous hybrids and about 400 registered cultivars (Benabdelkader et al. 2011). They are annual and herbaceous plants or small shrubs with aromatic foliage and flowers which differ by morphology, habitat, and chemical composition (Lesage-Meessen et al. 2015). Native to the Mediterranean region, lavenders are largely distributed and cultivated in Europe, Canary Islands, Madeira, North Africa, South West Asia, Arabian Peninsula, India, North, and South America (Lis-Balchin 2012; Benabdelkader et al. 2011). Due to their content in essential oils (EOs), *Lavandula* species are one of the most useful aromatic and medicinal plants with a great economic value for pharmaceutical, food, and flavor industries, cosmetics, perfumery, and aromatherapy (Zuzarte et al. 2009). The delightful fragrance of the plants is primarily due to the presence of monoterpenoids that are synthesized and accumulate in the aerial parts, mainly in flowers (Hassanpouraghdam et al. 2011). The most appreciated lavender oils for the perfume and cosmetic industries are those with high content in linalyl acetate and linalool and low content in camphor, while those richer in camphor are mainly used in aromatherapy and phytotherapy (Herraiz-Peñalver et al. 2013).

Three *Lavandula* species are principally cultivated for the commercial production of their essential oils, namely: *Lavandula angustifolia* Mill. syn. *L. officinalis* Chaix ex Vill syn. *L. vera* DC syn. *L. spica* L. (true lavender or fine lavender, English lavender), *Lavandula* × *intermedia* Emeric ex Loisel syn. *L hybrida* L. (lavandin), and *Lavandula latifolia* Medicus (spike lavender) (Lesage-Meessen et al. 2015). There are known over 50 cultivars of *L. angustifolia*, and some of the most popular cultivars include *Lady*, *Munstead*, *Hidcote* (Erland and Mahmoud 2016), *Royal Purple* (Lis-Balchin 2002), and *Royal Velvet* (Se 2013). Lavender essential oil has been found to exert significant clinical effects on the central nervous system (anxiolytic, sedative, anticonvulsant, analgesic, local anaesthetic activity), and it also showed antioxidant, antimicrobial, anti-inflammatory, spasmolytic, and carminative properties (Hassiotis et al. 2010). Lavandin is a natural steril hybrid that is derived from a cross of *L. angustifolia* × *L. latifolia* (Bajalan and Pirbalouti 2015) and it is produced in higher yields than true lavender essential oil (120 kg/ha compared to 40 kg/ha) (Carrasco et al. 2015a; Kara and Baydar 2013). High productivity of lavandin plants is determined, among others, by a larger storage capacity and different morphological features (localization and higher density of secretory structures such as peltate glandular trichomes) in comparison with fine lavande (Masetto et al. 2011). The *Abrial* (also known as *Abrialis*), *Grosso*, *Provence*, and *Super* are the most popular lavandin cultivars. Due to the high levels of camphor, lavandin essential oils are preferentially used in personal care and hygiene products, industrial and household cleaners, and also as antiseptic, antifungal agents and insecticides (Bajalan and Pirbalouti 2015; Kara and Baydar 2013). Spike lavender essential oil is traditionally known for its antibacterial, antifungal, sedative, carminative, anti-inflammatory, antidepressive activities, and it proved to be effective for burns and insect bites. Also, it is primarily used as raw material in industrial perfumes and fragrance industries, and as natural food flavouring agent (Muñoz-Bertomeu et al. 2007).

Several quality standards have been established regarding the chemical profile of lavender essential oils: ISO 3515:2002 (*Lavandula angustifolia* essential oil), ISO 8902:2009 (Lavandin *Grosso* essential oil, French type, ISO 3054:2001 (Lavandin *Abrial* essential oil, French type) and ISO 4719: (Spike lavender essential oil) (Table 1); also, pharmaceutical quality of true lavender essential oil is strictly regulated by Pharmacopoeias. The chemical composition and quality of lavender essential oils depend on many factors, such as: genotype, botanical part they are isolated from, and stage of plant development, soil and climatic conditions, harvesting time, drying methods, or extraction techniques (Duškova et al. 2016; Kara and Baydar 2013).

This paper provides a systematic view on the chemistry of lavender essential oils mainly considering the studies in the last 15 years. The review presents the characteristic constituents and chemotypes of each studied *Lavandula* species. The intra- and interspecific variability is discussed in relation to the geographic area, onto-and morphogenetic factors, and extraction methods. In addition, biosynthesis of lavender terpenes is presented.

Biosynthesis of terpenes from *Lavandula* species

The constituents of *Lavandula* essential oils (mono- and sesquiterpenes) are biosynthesized from the C5 units, isopenthenyl diphosphate (IPP) and its isomer, dimethylallyl diphosphate (DMAPP). They originate from acetyl coenzyme-A through the mevalonate (MVA) pathyway in the cytosol or 2C-methyl-D-erythritol 4-phosphate (MEP) route in the plastids. One molecule of IPP and one molecule of DMAPP are condensed to yield geranyl diphosphate (GPP), the precursor of most monoterpenes. Further condensation of one GPP with one IPP produces farnesyl diphosphate (FPP), the precursor of sesquiterpenes. The wide array of terpene skeletons results from the derivatization of GPP or FPP through the intervention of different terpene synthases (Fig. 1) (Chizzola 2013; Lange and Ahkam 2013; Boeckelmann 2008).

Content of essential oils in *Lavandula* species

An overview of the chemical studies published in the last 15 years reveals a huge variability in terms of lavenders essential oil content and composition (Tables 2, 3, 4). The variations are mainly influenced by cultivar, geographical location, altitude, soil and climate conditions, propagation, morphology, processing of the plant material and its nature—fresh or dried, extraction method. For *Lavandula angustifolia,* the content varied between 0.5 and 6.25% for fresh

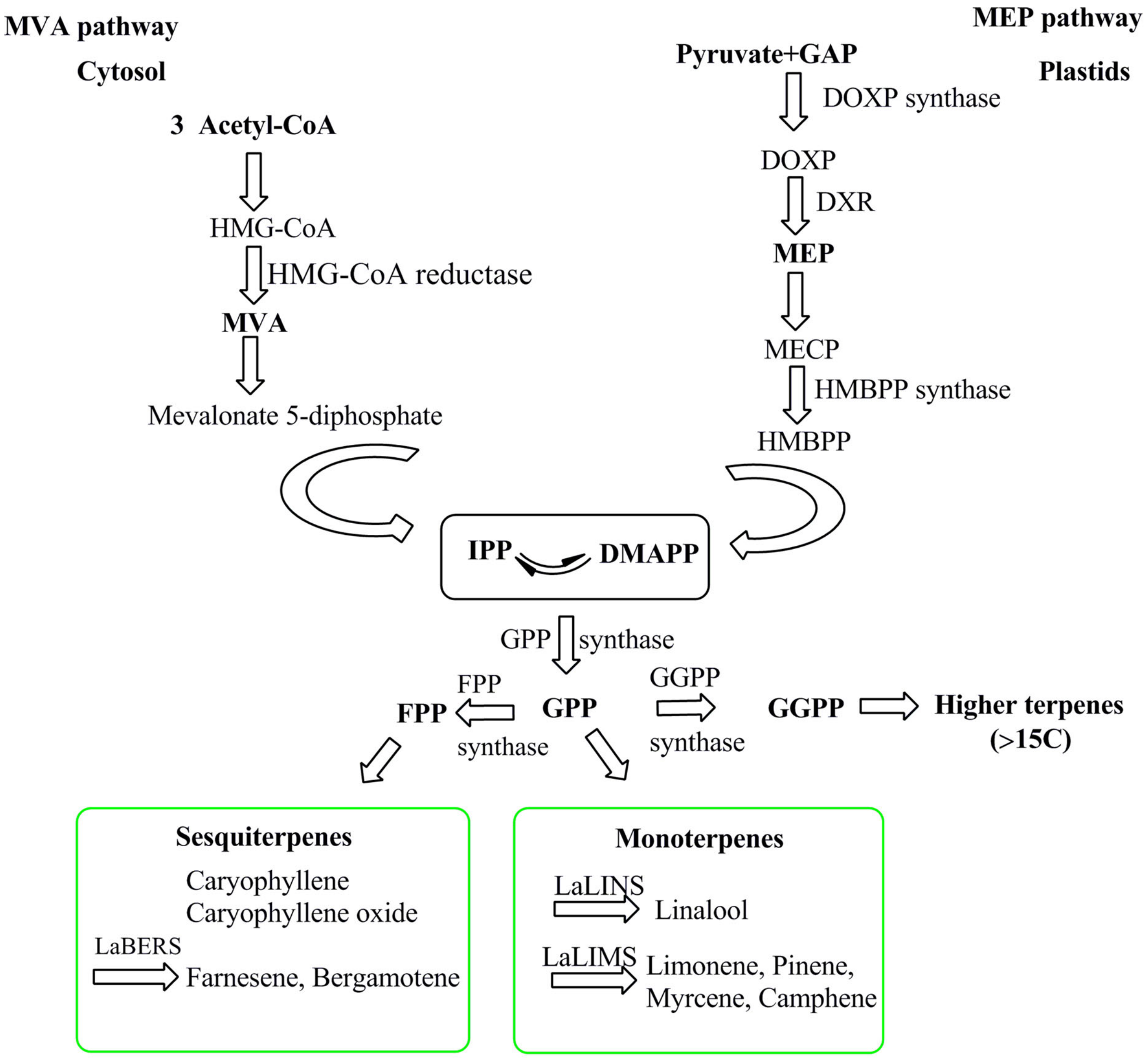
Table 1 ISO and pharmacopoeial standards (European Pharmacopoeia 6th 2008) for *Lavandula* sp. essential oils

Compound	ISO 3515:2002 *L. angustifolia*	ISO 8902:2009 Lavandin *Grosso*	ISO 3054:2001 Lavandin *Abrial*	ISO 4719:2012 *L. latifolia*	European Pharmacopoeia *L.angustifolia*
Linalool	25–38	24–35	26–38	34–50	20–45
Linalyl acetate	25–45	28–38	20–29	<1.6	25–46
1,8-Cineole	1–2	4–7	6–11	16–39	<2.5
Camphor	0.5–1	6–8	7–11	10–20	<1.2
Limonene	<1	0.5–1.5	0.5–1.5	0.5–3	<1
β-Ocimene	2.5–6	0.5–1.5	1.5–7	–	–
Terpinen-4-ol	2–6	1.5–5	0.3–1	–	0.1–0.6
Lavandulyl acetate	3.4–6.2	1.5–3	1–2	–	>0.2
Lavandulol	>0.1	0.2–0.8	0.4–1.2	–	>0.1
α-Terpineol	<2	–	–	0.2–2	<2
Borneol	–	1.5–3	1.5–3.5	–	–
α-Bisabolene	–	–	–	0.4–2.5	–
Pinene	–	–	–	1–3	–
3-Octanone	–	–	–	–	0.1–2.5

flowers, and between 0.5 and 9.62% for dry inflorescences (Table 2). The pharmaceutical requirement (European Pharmacopoeia 6th 2008) of minimum 1.3% essential oil in lavender inflorescences was not met in some of the cases. For *L.* × *intermedia*, the reported content was less than 3% for fresh material and between 3 and 9.9% for the dry product (Table 3). Very high levels of essential oil were reported in some Spanish populations of *L. latifolia* (8.74%) (Herraiz-Peñalver et al. 2013) or *L. viridis* from Portugal (9.27%) (Costa et al. 2012) (Table 4).

The cultivar significantly influences the essential oil content. For *L. angustifolia*, the highest values were reported for *Silver* variety cultivated in Turkey (9.62%). In the case of lavandins, the highest levels were determined for *Super* cultivar from Turkey and USA (8.97 and 10%, respectively) and *Grosso* cultivar grown in the USA (9.9%) (Kara and Baydar 2013; Renaud et al. 2001). A new variety of *L. angustifolia*, named *Etherio* and obtained by handmade pollinations between Greek native plants rich in essential oil, showed 78.8% higher oil content than native plants and had more blooms and branches (Hassiotis et al. 2010). Vegetative propagation in *Beta* Czech cultivar determined a higher essential oil content (3.80–8.95%) compared with propagation by seed in *Krajova* Czech cultivar (1.15–4.05%) (Duškova et al. 2016). Lavender plants grown at higher altitudes are richer in essential oil. Da Porto et al. (2009) reported a double content of essential oil for Italian lavender grown at 500 m compared with plants grown up to 20 m (1 vs. 0.5%). In general, it is considered that high production of true lavender essential oil requires a warm and dry climate and medium altitudes (700–1200 m) (Carrasco et al. 2015a). The essential oil content of some native populations of *L. angustifolia* grown in Greece at altitudes between 330 and 710 m varies between 0.44 and 1.89%. The south orientation of the land, with higher temperatures and lower rainfall, promotes synthesis of larger quantities of essential oil (1.21–1.89%) compared with the north orientation (0.44–0.81%) (Hassiotis et al. 2010). Greater amounts of essential oil accumulate in quiet and sunny weather, reaching up to 75% during blooming of plants (Stanev 2010).

The ontogenesis of the floral tissues also influences the essential oil accumulation and content in lavender species. For inflorescences of true lavender, the essential oil content is higher in button and preanthesis/anthesis, while for *L. dentata* (French/fringed lavender), in button stage (Masetto et al. 2011). In inflorescences of *L.* × *intermedia*, the essential oil content in anthesis and senescence, was 18 and 16%, respectively, higher than the content in pre-anthesis. Accumulation of essential oil in inflorescences of *Grosso* lavandin increases during floral development,



Acetyl-CoA, Acetyl coenzyme A; DMAPP, Dimethylallyl diphosphate; DOXP, 1-Deoxy-D-xylulose 5-phosphate; DXR,1-Deoxy-D-xylulose5-phosphate (DX) reductoisomerase; FPP, Farnesyl diphosphate; GAP, Glyceraldehyde 3-phosphate; GGPP, Geranyl geranyl diphosphate; GPP, Geranyl diphosphate; HMBPP, 1-Hydroxy-2-methyl-2-(E)-butenyl-4-diphosphate; HMG-CoA, 3-Hydroxy-3-methylglutaryl coenzyme A; IPP, Isopentenyl diphosphate; MECP, 2-C-methylerythritol-2,4-cyclodiphosphate; MVA, mevalonic acid; MEP, 2-C-methyl-D-erythritol-4-phosphate; LaBERS, Bergamotene synthase; LALINS, Linalool synthase; LALIMS, Limonene synthase.

Fig. 1 Biosynthesis of lavender terpenes (Chizzola 2013; Boeckelmann 2008)

reaching a maximum when the blossoms are at 30% of anthesis, then gradually decreases towards senescence (Masetto et al. 2011).

The leaves of *L. angustifolia*, *L. latifolia* and *L.* × *intermedia* have lower essential oil content than the flowers; the yield is 4–5 times higher in true lavender flowers than leaves; besides, flower oil has the finest fragrance (González-Rivera et al. 2016; Muñoz-Bertomeu et al. 2007). Guitton et al. (2010) showed that the leaves and bracts of *L. angustifolia* have about ten

Table 2 Content of essential oil (EO) (%) in *Lavandula angustifolia* plants (reported in studies from 2001 to 2016)

Plant material	Origin	EO content (%)	References
Fresh flowers/flowering aerial parts	Algeria (HD)	2	Belhadj Mostefa et al. (2014)
	France (SD)	0.8–0.87	NIIR (2011)
	Greece/cv. *Etherio* (SD)	2.61	Hassiotis et al. (2014)
	India (HD)	2.8	Verma et al. (2010)
	India (SD)	1.2–1.5	Panda (2005)
	Romania (SD)	1.13	Jianu et al. (2013)
	South Africa	0.7	NIIR (2011)
	Turkey (HD)	0.38–2	Kara and Baydar (2013)
	USA (SD)	0.5–6.8	Zheljazkov et al. (2013)
Fresh leaves with or without stems	Brazil (HD)	0.28	Mantovani et al. (2013)
	Italy (HD)	0.74	González-Rivera et al. (2016)
	Italy (CMHD)	0.75	
Dried flowers/flowering aerial parts	Argentina	0.8–1	NIIR (2011)
	Australia (HD)	4.57	Danh et al. (2013)
	Australia (SFE)	6.68	
	Australia (SE)	7.57	
	Bulgaria	1.6–2.6	Stanev et al. (2016)
	China (SFE)	4.8	Zhi-ling et al. (2011)
	China (MASD)	3.67	
	Czech Republic (HD)	1.15–8.95	Duškova et al. (2016)
	Egypt (HD)	1.4	Viuda-Martos et al. (2011)
	Greece (SE&HD)	0.44–1.89	Hassiotis et al. (2010)
	Greece cv. *Etherio*	5.90	
	India (HD)	1.37	Raina and Negi (2012)
	Iran (HD)	6.25	Hassanpouraghdam et al. (2011)
	Italy (HD)	0.5–1.02	Da Porto et al. (2009)
	Italy (SFE)	3.2–3.7	
	Italy (US)	0.21–0.35	
	Italy (SD)	8.75	Chemat et al. (2006)
	Italy (MASD)	8.86	
	Hungary (SD)	0.7–0.9	NIIR (2011)
	Poland (HD)	1.78–2.04	Seidler-Lozykowska et al. (2014)
	Poland (SD)	1–2	Wesolowska et al. (2010)
	Romania (HD)	3–5.62	Robu et al. (2011)
	Romania/ssp. *pyrenaica* (HD)	4	
	Serbia (HD)	6.47	Stanojevic et al. (2011)
	Turkey (HD)	2.30–9.62	Kara and Baydar (2013)
	UK	0.5–2	NIIR (2011)
	USA (SD)	6.14	Zheljazkov et al. (2013)
	USA (HD)	2.8–5	Renaud et al. (2001)
Flowering tops	Greece	4.4	Chatzopolou et al. (2003)
Dried leaves	Algeria (SD)	0.21	Djenane et al. (2012)

CMHD coaxial microwave assisted hydrodistillation, *HD* hydrodistillation, *MASD* microwave-assisted steam distillation, *SD* steam distillation, *SE* solvent extraction, *SFE* supercritical fluid extraction, *US* ultrasound-assisted extraction

Table 3 Content of essential oil (EO) (%) in *Lavandula* × *intermedia* plants (reported in studies from 2000 to 2016)

Plant material	Origin	EO content (%)	References
Fresh flowers/flowering aerial parts	Romania (SD)	2.73	Jianu et al. (2013)
	Turkey (HD)	1.12–1.67	Kara and Baydar (2013)
Dried flowers/flowering aerial parts	France (HD)	7.99–9.74	Kaloustian et al. (2000)
	France (SD)	4.49	Filly et al. (2016)
	France (HD)	4.55	
	France (MSD)	5.40	
	France/Cv. *Grosso* (HD)	5.4	Périno-Issartier et al. (2013)
	Romania (HD)	3	Robu et al. (2011)
	Spain (SD)	0.2–1.3	Carrasco et al. (2016)
	Turkey (HD)	5.87–8.37	Kara and Baydar (2013)
	USA (HD)	7.10–9.9	Renaud et al. (2001)
Flowering tops	Greece/cv. *Super* (HD)	7.5	Chatzopolou et al. (2003)
	Greece/cv. *Special* (HD)	8.5	
Dried leaves	France (HD)	0.39–0.80	Kaloustian et al. (2000)
	Iran (HD)	0.5–1.5	Bajalan and Pirbalouti (2015)

HD hydrodistillation, *MSD* microwave steam distillation, *SD* steam distillation

times less volatile compounds compared with the blooming heads, while the central inflorescence stem contains about ten times lower essential oil than the leaves. Also, the levels of volatile compounds in calyces and attached carpels are about 50 times higher than in corollas and stamens (Guitton et al. 2010). In the case of *L. dentata,* the essential oil content is higher in leaves than flowers during the floral development (Masetto et al. 2011). In the leaves of *L. angustifolia* and *L.* × *intermedia*, the essential oil content decreases with tissues aging (Masetto et al. 2011). For *L. latifolia* it appears that the Thermo-Mediterranean climate has a favorable influence on essential oil compared with Meso- and Supra-Mediterranean climate (4.40 mg/g dry plant material vs. 2.33 and 2.30 mg/g dry plant material, respectively) (Muñoz-Bertomeu et al. 2007).

Lavender essential oil content varies not only among species, but also within the same species, a large variability being reported for different populations as well as within the same population (Harborne and Williams 2002). Muñoz-Bertomeu et al. (2007) reported that, for natural populations of *L. latifolia* in eastern Iberian Peninsula, the proportion of variation attributable to individuals was significantly higher than that attributable to population differences. Benabdelkader et al. (2011) suggested that the large variations of essential oil content in wild populations of Algerian *L. stoechas* (0.34–1.63%), or for individuals from Spain, Crete, and Corsica may arise due to some inherent genetic differences or some uncontrolled biotic and abiotic elicitations.

The specific interaction between genotype and climatic conditions also affects the essential oil levels in lavenders. Stanev (2010) reported that some varieties of true lavender from Bulgaria (*Druzhba*, *Yubileina*, *Hebar*, *Sevtopolis*) showed an increased adaptability and high content of essential oil only in optimal pedo-climatic conditions, while others (*Helmus*, *Raya*) are characterized by stable yields regardless unfavorable climatic conditions.

The nature of plant material (fresh or dried), drying method and drying duration, and extraction method also cause variation of the essential oil content and composition. Supercritical fluid extraction of Italian true lavender can increase the essential oil yield by 3–6 times compared with hydrodistillation (3.2–3.7 vs. 0.5–1%) (Table 2) (Da Porto et al. 2009). Also, supercritical fluid extraction of Australian true lavender flowers led to an essential oil yield about 1.5 times higher in comparison with hydrodistillation (6.68 vs. 4.57%) (Danh et al. 2013). Zheljazkov et al. (2013) showed that, in the case of distillation of North American true lavender, the maximum yield is

Table 4 Content of essential oil (EO) (%) in other *Lavandula* species

Lavandula sp.	Origin	EO content (%)	References
L. coronopifolia	Jordan	0.6–7.2	Aburjai et al. (2005)
L. dentata	Algeria	0.24–1.34	Bousmaha et al. (2006)
		0.15–0.75	Bousmaha et al. (2005)
	Morocco	1.20–1.41	Imelouane et al. (2010)
	Yemen	0.58	Mothana et al. (2012)
L. gibsonii	India	0.14	Kulkarni et al. (2013)
L. latifolia	Spain	0.58–8.4	Herraiz-Peñalver et al. (2013)
		2.30–66.10 mg/g	Muñoz-Bertomeu et al. (2007)
		1.5–2.2	Salido et al. (2004)
L. lanata	Spain	0.8–2.4	Barrero et al. (2008)
L. luisieri	Portugal	0.12–0.79	González-Coloma et al. (2006)
	Spain	0.07–0.38	
		0.4	Julio et al. (2014)
	Algeria	0.01	Benbelaid et al. (2012)
L. multifida	Morocco	0.70	Sellam et al. (2013)
		2.01	N'Dédianhoua Soro et al. (2014)
L. pedunculata	Portugal	0.5–1.1	Zuzarte et al. (2010)
L. pubescens	Yemen	1.3	Nasser et al. (2013)
L. stoechas	Algeria	1.1	Dob et al. (2006)
	France	0.1–0.75	Ristorcelli et al. (1998)
	Greece	1.46	Hassiotis (2010)
		1.2–4.2	Skoula et al.1996
	Spain	0.3–1	Carrasco et al. (2015b)
	Tunisia	0.77	Bouzouita et al. (2005)
	Turkey	1.61	Giray et al. (2008)
		0.71–1.97	Kaya et al. (2012)
L. viridis	Portugal	0.53–9.27	Costa et al. (2012)
		0.7–1.2	Zuzarte et al. (2011)

achieved after 60 min (over 6%). Prolonged storage of dried lavender flowers before hydrodistillation causes a reduction in essential oil content of about 0.007%/day, or around 2.56%/year (Duškova et al. 2016).

Chemical composition of Lavandula essential oils

Among the 39 *Lavandula* species, only 17 species were investigated in terms of chemical composition of their essential oils (*L. angustifolia, L. × intermedia, L. latifolia, L. stoechas, L. bipinnata, L. canariensis, L. coronopifolia, L. dentata, L. heterophylla, L. gibsonii, L. lanata, L. luisieri, L. multifida, L. pedunculata, L. pinnata, L. pubescens, L. viridis*). *L. angustifolia* was the most studied species. More than 300 terpenes (mono- and sesquiterpenes) have been reported in *Lavandula spp*. (Lis-Balchin 2012). The structural diversity of these compounds is highly variable depending on the species. For example, if *L. angustifolia* or *L. stoechas* biosynthesize about 60–100 different terpenes and *L. latifolia* produces more 300 terpenes, *L. canariensis* has a lower diversity (Lis-Balchin 2012; Benabdelkader 2012). At the same time, studies highlighted a large intraspecific variability, mainly quantitative. The constituents of lavender essential oils (Fig. 2) are discussed dependent on the chemical classes and the species especially considering the studies in the last 15 years around the world.

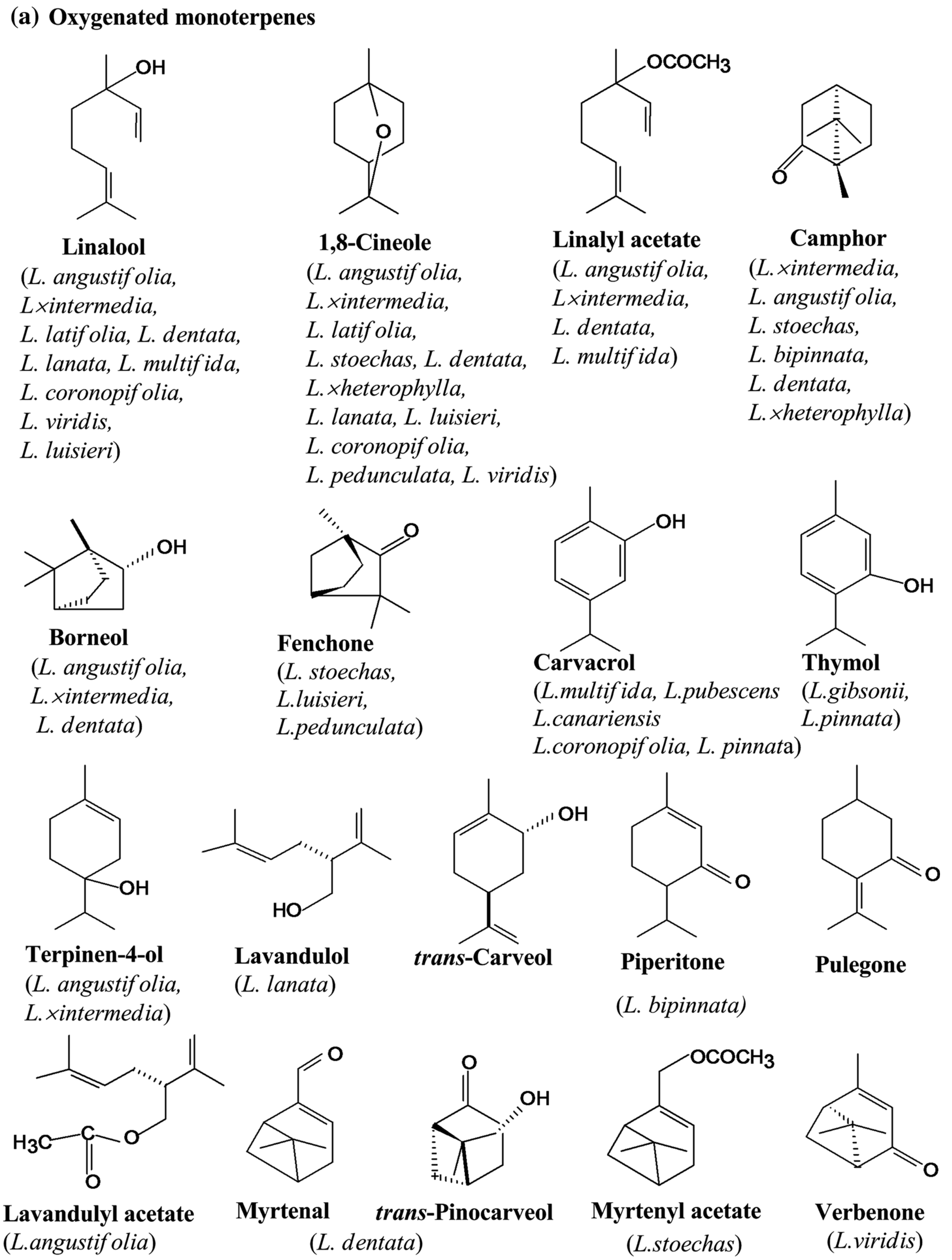
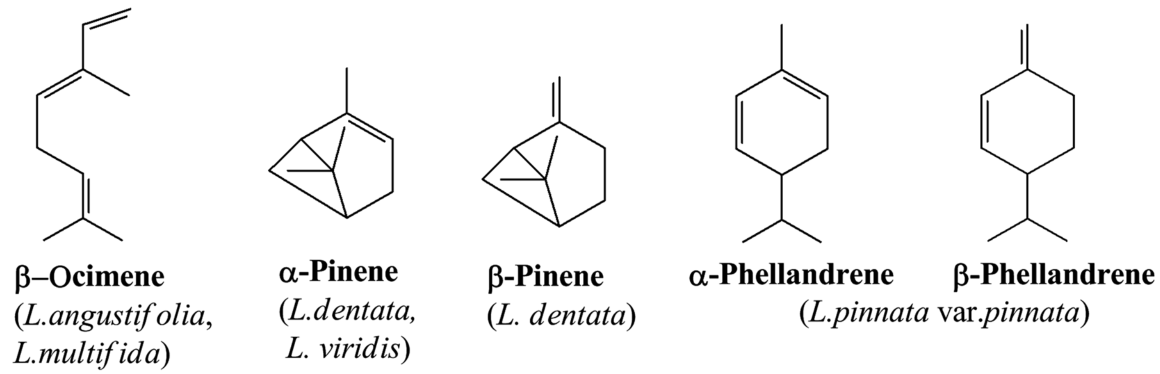
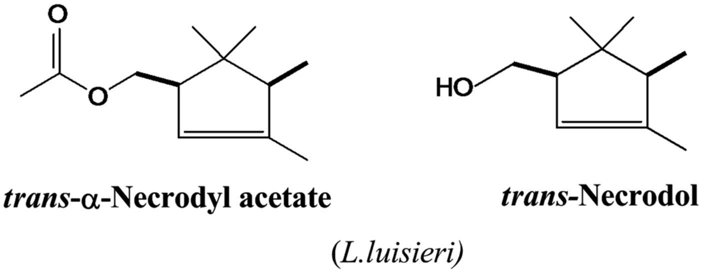


Fig. 2 Major compounds of *Lavandula sp.* essential oils. **a** Oxygenated monoterpenes. **b** Monoterpene hydrocarbons. **c** Irregular monoterpenoids. **d** Sesquiterpenes

(b) Monoterpene hydrocarbons



(c) Irregular monoterpenoids



(d) Sesquiterpenes

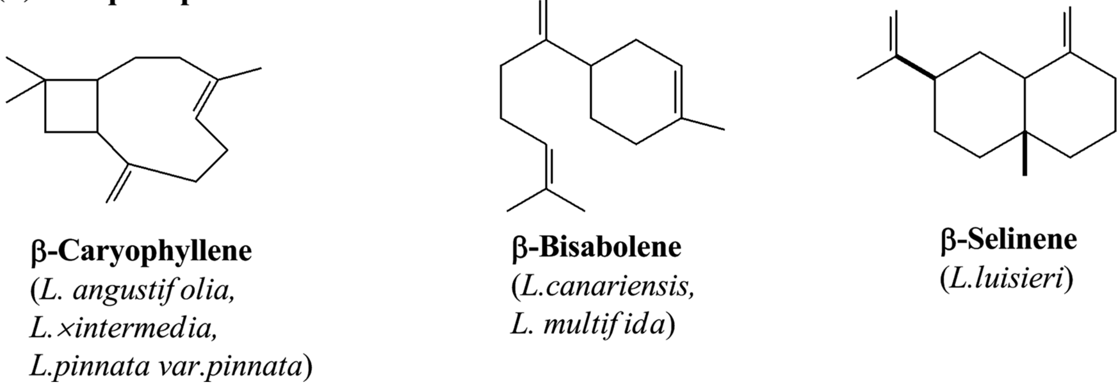


Fig. 2 continued

Monoterpenoids

Oxygenated monoterpenes constitute the bulk of the essential oils isolated from flowers of *Lavandula* species. They can exceed 90% for *L. angustifolia* (36.33–92.90%), *L.* × *intermedia* (68.3–93.10%), *L. stoechas* (46.19–92.93%) and *L. latifolia* (85.2–94.10%). High values (over 70%) are also characteristic for *L. pedunculata* (58.20–89%), *L. luisieri* (16.7–85.21%), *L. viridis* (65.29–75.70%) and

L. dentata (56.50–71.80%). The higher amounts of monoterpenoids support the intense activity of plastidal hydroxylases and dehydrogenases involved in the conversion of the terpene hydrocarbons (Hassanpouraghdam et al. 2011). Oxygenated terpenes have significant pharmacological and sensory qualities (Table 5) being responsible for the valuable scent of lavender. Generally, true lavender EO has a sweet floral, herbaceous, refreshing odour with a pleasant, balsamic-wood undertone, and a fruity-sweet top note, lavandin EOs are characterized by a strong herbaceous odour with a distinct fresh camphene cineole-like top-note (Lis-Balchin 2012) while spike lavender EO presents a floral fresh, sweet, herbaceous, slightly spicy smell. *L. stoechas* EO has a warm, sweet floral, slightly fruity and camphorous fragrance and *L.* × *heterophylla* Goodwin Creek presents an atypical aroma, more floral with a warm-rosy note and less herbaceous than the others (Lis-Balchin 2012). The essential oil of *L. multifida* (fernleaf lavender, Egyptian lavender) displays a warm and balsamic aroma.

The most common monoterpenoids of lavender EOs are alcohols (linalool, terpinen-4-ol, α-terpineol, borneol, lavandulol), esters (linalyl acetate, lavandulyl

Table 5 Sensory qualities of terpenes from *Lavandula* sp. essential oils (Wiesenfeld 1999; Chizzola 2013)

Category	Compound	Sensory character
Monoterpenoids	Borneol	Woody-camphoraceaous, dry minty
	Camphor	Camphoraceous, fresh, warm-minty
	Citronellol	Sweet roselike
	1,8-Cineole	Fresh-mint-like, camphoraceous
	Fenchone	Camphor-like, powerful and sweet
	Geraniol	Floral, lemon-like, minty
	Geranyl acetate	Fruity rose
	Lavandulol	Warm-rosy cu a slightly spicy note
	Lavandulyl acetate	Fresh-herbal rose
	Linalool	Fresh, floral, sweet, lemon notes
	Linalyl acetate	Floral, herbal, bergamot, lavender and woody
	Nerol	Rose, sweet
	Neryl acetate	Floral, rose, fruity
	Terpinen-4-ol	Nutmeg-like, spicy, woody-earthy, liliac-like
	α-Terpineol	Floral, lilac-like
Monoterpenes	β-Phellandrene	Peppery-minty, slightly citrusy
	Limonene	Fresh, citrus-like, mild lemon, orange notes
	Myrcene	Mild, sweet, balsamic note
	Cis-β-Ocimene	Herbal, warm-herbaceous, sweet-floral, nerol-like
	Trans-β-Ocimene	Herbal, weak floral
	α-Pinene	Pine-like, sharp, woody, turpentine-like
	β-Pinene	Dry-woody, pine-like, resinous-terpene-like, spicy
Sesquiterpenes	*Trans*-α-Bergamotene	Weak woody, warm, tea-leaf like
	α-Bisabolol	Sweet, mild floral
	β-Bisabolene	Sweet spicy balsamic
	α-Cadinol	Weak woody, medicinal, dry
	β-Caryophyllene	Woody, spicy
	Caryophyllene oxide	Weak woody, warm, mild, weak spicy
	Trans-β-Farnesene	Warm, mild, sweet
	Germacrene D	Weak spicy, weak fruity, apple-like, weak dry-woody
	γ-Muurolene	Weak spicy, weak woody, mild

Table 6 Overview of studies (2001–2016) on chemical composition of *Lavandula angustifolia* EOs

Main compounds	Plant material used for EO isolation	Concentration	References
Linalool	DF	53.5% (Argentina)	Martucci et al. (2015)
	DF	53.4% (USA/var. *Lady*)	Renaud et al. (2001)
	DF	33.35–52.59% (Australia)	Danh et al. (2013)
	F	50.63% (Greece)	Chatzopolou et al. (2003)
	FF	48.71% (Greece/var. *Etherio*)	Hassiotis et al. (2014)
	DF	46.85–47.82% (Italy)	Chemat et al. (2006)
	FF	12.32–47.29% (Bulgaria)	Milina et al. (2012)
	DF	32.78–45.78% (Italy)	Da Porto et al. (2009)
	NS	44.54% (China)	Cong et al. (2008)
	DA	18.70–43.47% (Korea/var. *Hidcote*)	Kim and Lee (2002)
	FF	33.62–42.56 (Romania)	Călinescu et al. (2014)
	DF	26.46–41.04% (Czech Republic)	Duškova et al. (2016)
	DF	39.83% (Egypt)	Viuda-Martos et al. (2011)
	DF	27–38.7 (England)	Se (2013)
	DF	38.3% (USA/var. *Munstead*)	Renaud et al. (2001)
	DF	37.8% (USA/var. *English*)	Renaud et al. (2001)
	DF	22.2–36.8 (France)	Se (2013)
	DF	27–35.5% (Australia-Tasmania)	Se (2013)
	DA	32.8–35.3% (Iran)	Fakhari et al. (2005)
	DA	35.01% (Serbia)	Miladinović et al. (2012)
	DF	34.5% (USA/var. *Grey Lady*)	Renaud et al. (2001)
	FF	18.7–34.4% (Bulgaria)	Zagorcheva et al. (2013)
	DF	33.7% (Iran)	Hassanpouraghdam et al. (2011)
	FF	25.4–31.8% (USA)	Zheljazkov et al. (2012)
	DF	30.6% (Poland)	Smigielski et al. (2009)
	DF	19–30.3% (USA)	Se (2013)
	DF	29.1% (USA/var. *Hidcote*)	Renaud et al. (2001)
	FF	28.6% (India)	Verma et al. (2010)
	DF	21.2–26.6% (USA)	Zheljazkov et al. (2012)
	DF	25% (USA/var. *Royal Velvet*)	Se (2013)
	DA	1.26–24.77% (Czech Republic)	Sajfrtova et al. (2013)
	F	24.63% (Irak)	Hamad et al. (2013)
	DA	23.60% (India)	Raina and Negi (2012)
	DL	22.35% (Algeria)	Djenane et al. (2012)
	DF	3.59–8.14% (Italy)	Binello et al. (2014)
	DF	5.9% (Egypt)	Tarek et al. (2014)
	DL	4.91% (Iran)	Yazdani et al. (2013)
	LS	5.76% (Poland/var. *Ellegance Purple*)	Adaszynska-Skwirzynska et al. (2014)
	LS	4.90% (Poland var. *Blue River*)	Adaszynska-Skwirzynska et al. (2014)
	DF	2.8% (USA/var. *Alba*)	Renaud et al. (2001)
	FL + FS	1.8–2.2% (Italy)	González-Rivera et al. (2016)
	FA	1.1% (Algeria)	Belhadj Mostefa et al. (2014)

Table 6 continued

Main compounds	Plant material used for EO isolation	Concentration	References
Linalyl acetate	DF	56.7% (USA/var. *Royal Velvet*)	Se (2013)
	DF	43.4–52.2% (England)	Se (2013)
	DF	47–50.3% (France)	Se (2013)
	DF	43.1–50.3% (Australia-Tasmania)	Se (2013)
	DF	44–48.1% (USA)	Se (2013)
	DA	2.63–48.06% (Korea)	Kim and Lee (2002)
	FF	47.56% (India)	Verma et al. (2010)
	DF	39.6–40.5% (USA)	Zheljazkov et al. (2012)
	DF	38.23% (Serbia)	Miladinović et al. (2012)
	FF	16.85–37.63% (Bulgaria)	Milina et al. (2012)
	DA	12.29–36.33% (Czech Republic)	Sajfrtova et al. (2013)
	DA	35.80% (India)	Raina and Negi (2012)
	FF	33.16–34.11% (Romania)	Călinescu et al. (2014)
	FF	20.7–32.7% (Bulgaria)	Zagorcheva et al. (2013)
	DF	32.21% (Egypt)	Viuda-Martos et al. (2011)
	FF	26.5–30.6% (USA)	Zheljazkov et al. (2012)
	DF	28.88% (Czech Republic/var. *Beta*)	Duškova et al. (2016)
	DL	21.80% (Algeria)	Djenane et al. (2012)
	DF	14.42–21.74% (Italy)	Da Porto et al. (2009)
	FF	21.30% (Greece var. *Etherio*)	Hassiotis et al. (2014)
	DF	9.27–25.73% (Australia)	Danh et al. (2013)
	DF	19.07% (Czech Republic/var. *Krajova*)	Duškova et al. (2016)
	DA	13.4–17.6% (Iran)	Fakhari et al. (2005)
	DF	17.3% (USA/var. *Hidcote*)	Renaud et al. (2001)
	DF	16.8% (USA/var. *Alba*)	Renaud et al. (2001)
	F	15.72% (Greece)	Chatzopolou et al. (2003)
	DF	15% (USA/var. *Munstead*)	Renaud et al. (2001)
	DF	14.7% (USA/var. *English*)	Renaud et al. (2001)
	DF	14.3% (USA/var. *Grey Lady*)	Renaud et al. (2001)
	DF	14.2% (Poland)	Smigielski et al. (2009)
	DF	10.74–11.90% (Italy)	Chemat et al. (2006)
	F	8.89% (Irak)	Hamad et al. (2013)
	DF	6.9% (Egypt)	Tarek et al. (2014)
	DF	5.1% (USA/var. *Lady*)	Renaud et al. (2001)
	DA	4.2% (Argentina)	Martucci et al. (2015)
1,8-Cineole	DL, DS	33.3–44.4% (Italy)	González-Rivera et al. (2016)
	DL	42.47% (Brazil)	Cassel et al. (2009)
	DL	31.9% (Iran)	Hassanpouraghdam et al. (2011)
	FF	29.4% (Algeria)	Belhadj Mostefa et al. (2014)
	DF	28.3% (Brazil)	Maia et al. (2004)
	DL	17.1% (Iran)	Hassanpouraghdam et al. (2011)
	FF	15.69% (Romania)	Călinescu et al. (2014)
	DF	3.98–14.24% (Italy)	Da Porto et al. (2009)
	DF	10.9% (USA/var. *Royal Velvet*)	Se (2013)

Table 6 continued

Main compounds	Plant material used for EO isolation	Concentration	References
	DA	4.77–8.25% (Korea var. *Hidcote*)	Kim and Lee (2002)
	DL	7.9% (Brazil)	Mantovani et al. (2013)
	DF	7.23–7.29% (Italy)	Chemat et al. (2006)
	F	7.14% (Irak)	Hamad et al. (2013)
	DA	6.8% (Argentina)	Martucci et al. (2015)
	DL,DS	6.19% (Poland/var. *Blue River*)	Adaszynska-Skwirzynska et al. (2014)
	DF	1.7–6.2% (USA)	Se (2013)
	DA	6.7% (Iran)	Fakhari et al. (2005)
	FF	0.31–4.23% (Bulgaria)	Milina et al. (2012)
	DA	3.99% (Serbia)	Miladinović et al. (2012)
	DL	3.92% (Iran)	Yazdani et al. (2013)
	DL, DS	3.66% (Poland/var. *Ellegance Purple*)	Adaszynska-Skwirzynska et al. (2014)
	FF	2.6% (Greece var. *Etherio*)	Hassiotis et al. (2014)
	DF	2% (Poland)	Smigielski et al. (2009)
	DF	1.9% (Australia–Tasmania)	Se (2013)
	DF	1.7% (USA)	Se (2013)
	DF	1.5% (USA/var. *Munstead*)	Renaud et al. (2001)
	DF	1.2% (USA/var. *Hidcote*)	Renaud et al. (2001)
	DF	1% (USA/var. *Alba*, *English*)	Renaud et al. (2001)
Camphor	DF	28% (Brazil)	Maia et al. (2004)
	FF	24.6% (Algeria)	Belhadj Mostefa et al. (2014)
	DL, DS	23.1–25.1% (Italy)	González-Rivera et al. (2016)
	DL	16.1% (Iran)	Hassanpouraghdam et al. (2011)
	DF	5.56–13.64% (Italy)	Da Porto et al. (2009)
	F	13.58% (Irak)	Hamad et al. (2013)
	DF	10.23–11.82% (Italy)	Chemat et al. (2006)
	DF	11.29% (Egypt)	Viuda-Martos et al. (2011)
	DL	10.85% (Brazil)	Cassel et al. (2009)
	DF	6.8–9.4% (USA)	Se (2013)
	DF	6.81–8.79% (Australia)	Danh et al. (2013)
	DA	8.4% (Argentina)	Martucci et al. (2015)
	DF	7.8% (Iran)	Hassanpouraghdam et al. (2011)
	DF	6.12% (Egypt)	Tarek et al. (2014)
	DA	3.99% (Serbia)	Miladinović et al. (2012)
	FF	3.62% (Greece var. *Etherio*)	Hassiotis et al. (2014)
	DA	3.55% (Italy)	Binello et al. (2014)
	FL	3.5% (Brazil)	Mantovani et al. (2013)
	DF, DS	2.58% (Poland/var. *Blue River*)	Adaszynska-Skwirzynska et al. (2014)
	DF, DS	2.52% (Poland/var. *Ellegance Purple*)	Adaszynska-Skwirzynska et al. (2014)
	DA	1.9% (Iran)	Fakhari et al. (2005)

Table 6 continued

Main compounds	Plant material used for EO isolation	Concentration	References
β-Caryophyllene	FF	24.12% (Romania)	Jianu et al. (2013)
	FF	0.83–5.19% (Bulgaria)	Milina et al. (2012)
	DL	4.83% (Algeria)	Djenane et al. (2012)
	DF	4.7% (Poland)	Smigielski et al. (2009)
	FF	2.67–4.33% (Romania)	Călinescu et al. (2014)
	DA	4.30% (Serbia)	Miladinović et al. (2012)
	DF	4.3% (USA/var. *Alba*)	Renaud et al. (2001)
	DF	2.36–3.96% (Italy)	Da Porto et al. (2009)
	FF	1–3.8% (Bulgaria)	Zagorcheva et al. (2013)
	DF	3.8% (USA/var. *English*)	Renaud et al. (2001)
	DF	3.7% (USA/var. *Grey Lady*)	Renaud et al. (2001)
	DF	3.5% (USA/var. *Munstead*)	Renaud et al. (2001)
	DA	1.82–3.35% (Czech Republic)	Sajfrtova et al. (2013)
	FL	3.2% (Brazil)	Mantovani et al. (2013)
	DF	3% (USA/var. *Hidcote*)	Renaud et al. (2001)
	DF	2.9% (France)	Se (2013)
	DF	2.4% (England)	Se (2013)
	DF	2.14% (Australia)	Danh et al. (2013)
	F	2.04% (Greece)	Chatzopolou et al. (2003)
	DF	1.5% (USA/var. *Lady*)	Renaud et al. (2001)
Borneol	DL	24% (Iran)	Hassanpouraghdam et al. (2011)
	FL	22.4% (Brazil)	Mantovani et al. (2013)
	DF	14.7% (Iran)	Hassanpouraghdam et al. (2011)
	DL, DS	13.84% (Poland/var. *Blue River*)	Adaszynska-Skwirzynska et al. (2014)
	DA	7.14–13.72% (Italy)	Binello et al. (2014)
	DL, DS	12.43% (Poland/var. *Ellegance Purple*)	Adaszynska-Skwirzynska et al. (2014)
	DA	1.88–11.37% (Korea/var. *Hidcote*)	Kim and Lee (2002)
	DL	8.57% (Iran)	Yazdani et al. (2013)
	DF	6.68–7.50% (Australia)	Danh et al. (2013)
	F	6.41% (Irak)	Hamad et al. (2013)
	DF	2.71–6.77% (Italy)	Da Porto et al. (2009)
	DF	5.2% (USA)	Se (2013)
	FF	5.07% (Romania)	Jianu et al. (2013)
	DA	4.7% (Argentina)	Martucci et al. (2015)
	DF	4.07–4.15% (Italy)	Chemat et al. (2006)
	FF	4.1% (Algeria)	Belhadj Mostefa et al. (2014)
	FF	4.08% (Greece/var. *Etherio*)	Hassiotis et al. (2014)
	DA	3.1–3.8% (Iran)	Fakhari et al. (2005)
	DF	2.4–3.3% (USA)	Zheljazkov et al. (2012)
	DA	2.84% (Serbia)	Miladinović et al. (2012)
	DF	2.5% (England)	Se (2013)
	DL	2.1% (Algeria)	Djenane et al. (2012)

Table 6 continued

Main compounds	Plant material used for EO isolation	Concentration	References
	DF	2% (Poland)	Smigielski et al. (2009)
	DF	1.4% (Australia-Tasmania)	Se (2013)
Cis-β-Ocimene	FF	1.70–18.40% (Bulgaria)	Milina et al. (2012)
	F	7.59% (Irak)	Hamad et al. (2013)
	F	4.25% (Greece)	Chatzopolou et al. (2003)
	DF	3.9% (Poland)	Smigielski et al. (2009)
	DL	3.63% (Algeria)	Djenane et al. (2012)
	DF	1.6% (England)	Se (2013)
Δ-Carene	DF	17.14% (Egypt)	Tarek et al. (2014)
Lavandulyl acetate	DA	10.9–15.9% (Iran)	Fakhari et al. (2005)
	NS	10.78% (China)	Cong et al. (2008)
	DF	8.62% (Czech Republic/var. *Krajova*)	Duškova et al. (2016)
	DF	6.3% (USA/var. *English*)	Renaud et al. (2001)
	DF	5.4% (USA/var. *Munstead*)	Renaud et al. (2001)
	DF	5.3% (USA/var. *Hidcote*)	Renaud et al. (2001)
	DL	4.99% (Algeria)	Djenane et al. (2012)
	DA	4.80% (India)	Raina and Negi (2012)
	FF	2.45–4.43% (Bulgaria)	Milina et al. (2012)
	DF	4.4% (Poland)	Smigielski et al. (2009)
	FF	4.34% (India)	Verma et al. (2010)
	DA	1.51–3.92% (Czech Republic)	Sajfrtova et al. (2013)
	DF	3.8% (USA/var. *Alba*)	Renaud et al. (2001)
	DF	3.7% (England)	Se (2013)
	FF	3.48% (Romania)	Călinescu et al. (2014)
	DF	3.2% (USA/var. *Grey Lady*)	Renaud et al. (2001)
	DF	3.2% (France)	Se (2013)
	F	2.73% (Greece)	Chatzopolou et al. (2003)
	DF	1.2% (USA/var. *Lady*)	Renaud et al. (2001)
α-Fenchone	DF	16.79% (Egypt)	Tarek et al. (2014)
	FL	14.96% (Brazil)	Cassel et al. (2009)
	DA	4.67% (Korea/var. *Hidcote*)	Kim and Lee (2002)
Coumarin	DA	9.41–16.59% (Italy)	Binello et al. (2014)
	DA	7.42% (Korea/var. *Hidcote*)	Kim and Lee (2002)
β-Phellandrene	FF	16% (Romania)	Jianu et al. (2013)
Terpinen-4-ol	DA	4.63–14.01% (Korea/var. *Hidcote*)	Kim and Lee (2002)
	FF	9.57% (Romania)	Jianu et al. (2013)
	F	7.84% (Greece)	Chatzopolou et al. (2003)
	DF	7–7.8% (France)	Se (2013)
	DA	7.6% (Argentina)	Martucci et al. (2015)
	DA	1.21–6.70% (Czech Republic)	Sajfrtova et al. (2013)
	DF	2.49–6.57% (Italy)	Da Porto et al. (2009)
	DF	3.2–6.2% (England)	Se (2013)
	DF	5.54–5.94% (Italy)	Chemat et al. (2006)
	DA	5.45% (Czech Republic/var. *Beta*)	Duškova et al. (2016)

Table 6 continued

Main compounds	Plant material used for EO isolation	Concentration	References
	FF	1.30–4.60% (Bulgaria)	Milina et al. (2012)
	DA	4.35% (Czech Republic/var. *Krajova*)	Duškova et al. (2016)
	DF	3.8% (USA/var. *Royal Velvet*)	Se (2013)
	DF	3.5% (Iran)	Hassanpouraghdam et al. (2011)
	DF	3.4% (Poland)	Smigielski et al. (2009)
	DF	3.3% (USA)	Se (2013)
	FF	3.01–3.23% (Romania)	Călinescu et al. (2014)
	DF	2.8% (Australia-Tasmania)	Se (2013)
	DA	2.12–2.45% (Australia)	Danh et al. (2013)
	DA	2% (India)	Raina and Negi (2012)
Epi-α-Muurolol	FL	13.4% (Brazil)	Mantovani et al. (2013)
α-Bisabolol	FL, FS	6.5–14.1% (Italy)	González-Rivera et al. (2016)
	FL	13.1% (Brazil)	Mantovani et al. (2013)
	DF	6.75–11.87% (Italy)	Da Porto et al. (2009)
	DL	2.31% (Iran)	Fakhari et al. (2005)
Trans-β-Ocimene	FF	0.55–13.03% (Bulgaria)	Milina et al. (2012)
	DL	6.16% (Algeria)	Djenane et al. (2012)
	F	4.76% (Irak)	Hamad et al. (2013)
	F	2.73% (Greece)	Chatzopolou et al. (2003)
	DF	2.3% (Poland)	Smigielski et al. (2009)
	DA	2.09% (Czech Republic)	Sajfrtova et al. (2013)
Precocene I	FL	13% (Brazil)	Mantovani et al. (2013)
7-Methoxycoumarin	DA	2.93–11.81% (Italy)	Binello et al. (2014)
	DA	1.32% (Korea/var. *Hidcote*)	Kim and Lee (2002)
Geraniol	NS	11.02% (China)	Cong et al. (2008)
	DF	5.3% (Poland)	Smigielski et al. (2009)
	DA	3.3% (India)	Raina and Negi (2012)
3,7-Dimethyl-2,6-octadien-1-ol	NS	10.78% (China)	Cong et al. (2008)
Isoborneol	DF	9.9% (Brazil)	Maia et al. (2004)
α-Terpineol	DF	9.17% (Czech Republic/var. *Beta*)	Duškova et al. (2016)
	DA	6.3% (India)	Raina and Negi (2012)
	DF	6.11% (Czech Republic/var. *Krajova*)	Duškova et al. (2016)
	FF	6% (Romania)	Jianu et al. (2013)
	DA	5.82% (Czech Republic)	Sajfrtova et al. (2013)
	DA	2.58–4.61% (Korea/var. *Hidcote*)	Kim and Lee (2002)
	FF	4.6% (Greece/var. *Etherio*)	Hassiotis et al. (2014)
	FF	3.31–4.38% (Romania)	Călinescu et al. (2014)
	FF	3.75% (India)	Verma et al. (2010)
	DF	3.03% (Australia)	Danh et al. (2013)
	DF	2.17% (Poland)	Smigielski et al. (2009)
	DL	2.08% (Algeria)	Djenane et al. (2012)
	FL, FS	2% (Italy)	González-Rivera et al. (2016)

Table 6 continued

Main compounds	Plant material used for EO isolation	Concentration	References
Caryophyllene oxide	DL, DS	8.68% (Poland/var. *Ellegance Purple*)	Adaszynska-Skwirzynska et al. (2014)
	DL, DS	7.98% (Poland/var. *Blue River*)	Adaszynska-Skwirzynska et al. (2014)
	DF	5% (USA)	Zheljazkov et al. (2012)
	DA	2.48–4.26% (Italy)	Binello et al. (2014)
	DA	1.8–3.53% (Korea/var. *Hidcote*)	Kim and Lee (2002)
	DF	2.1% (Poland)	Smigielski et al. (2009)
	DA	1.9% (Iran)	Fakhari et al. (2005)
Epibicyclosesquiphellandrene	DL, DS	8.26% (Poland/var. *Ellegance Purple*)	Adaszynska-Skwirzynska et al. (2014)
	DL, DS	6.82% (Poland/var. *Blue River*)	Adaszynska-Skwirzynska et al. (2014)
Limonene	DF	7.63% (Egypt)	Tarek et al. (2014)
	FF	0.19–3.74% (Bulgaria)	Milina et al. (2012)
	DF	2.36% (Italy)	Da Porto et al. (2009)
	DL, DS	2.25% (Poland/var. *Blue River*)	Adaszynska-Skwirzynska et al. (2014)
3-Octanone	FF	1.46–7.52% (Bulgaria)	Milina et al. (2012)
	DF	4.9% (Australia-Tasmania)	Se (2013)
Isoterpineol	NS	6.75% (China)	Cong et al. (2008)
Pinene	FF	4.27–6.63% (Romania)	Călinescu et al. (2014)
	DF	4.75% (α) (Egypt)	Tarek et al. (2014)
	FL, FS	4.1% (β)(Italy)	González-Rivera et al. (2016)
	FL, FS	3.62% (β)(Poland/var. *Ellegance Purple*)	Adaszynska-Skwirzynska et al. (2014)
	DL, DS	3.54% (β)(Poland/var. *Blue River*)	Adaszynska-Skwirzynska et al. (2014)
	FL, FS	2.5–3.4% (α) (Italy)	González-Rivera et al. (2016)
	FA	3.2% (β); 1.6% (α) (Algeria)	Belhadj Mostefa et al. (2014)
	FL	3.07% (α) (Brazil)	Mantovani et al. (2013)
2,6-Dimethyl-3,5,7-octatriene-2-ol	F	5.39% (Irak)	Hamad et al. (2013)
α-Phellandrene	DF	5.7% (Brazil)	Maia et al. (2004)
Geranyl acetate	DA	2.5–5% (Iran)	Fakhari et al. (2005)
	DL, DS	4.11% (Poland/var. *Ellegance Purple*)	Adaszynska-Skwirzynska et al. (2014)
	DL, DS	4.01% (Poland/var. *Blue River*)	Adaszynska-Skwirzynska et al. (2014)
	DA	2.7% (Czech Republic)	Sajfrtova et al. (2013)
β-Farnesene	FF	1–4.65% (Bulgaria)	Milina et al. (2012)
	DF	3.56–4.50% (Australia)	Danh et al. (2013)
	DF	2.15–4.02% (Italy)	Da Porto et al. (2009)
	DL	2.87% (Algeria)	Djenane et al. (2012)
	DA	1.75–2.78% (Czech Republic)	Sajfrtova et al. (2013)
	DA	2.60% (Korea/var. *Hidcote*)	Kim and Lee (2002)

Table 6 continued

Main compounds	Plant material used for EO isolation	Concentration	References
Endo-Fenchol	FL	4.6% (Brazil)	Mantovani et al. (2013)
Santalene	FF	4.5% (Romania)	Jianu et al. (2013)
	DL, DS	2.63% (Poland/var. *Blue River*)	Adaszynska-Skwirzynska et al. (2014)
	DL, DS	2.35% (Poland/var. *Blue River*)	Adaszynska-Skwirzynska et al. (2014)
Lavandulol	DA	3–4.3% (Iran)	Fakhari et al. (2005)
	DF	2.1% (France)	Se (2013)
Camphene	NS	3.98% (China)	Cong et al. (2008)
	FA	1.5% (Algeria)	Belhadj Mostefa et al. (2014)

DA dried aerial parts, *DF* dried flowers, *DL* dried leaves, *DS* dried stems, *F* flowers, *FF* fresh flowers, *FL* fresh leaves, *FS* fresh stems, *NS* nespecified

acetate, geranyl acetate, geranyl propionate), ketones (camphor, fenchone, thujone), and oxides (1,8-cineole).

Linalool and linalyl acetate

They are the main compounds in the essential oils of *L. angustifolia* (1.1–53.5 and 4.2–56.70%, respectively) (Table 6) and *L.* × *intermedia* (1.7–47.51 and 1.5–48.2%, respectively) (Table 7). Also, linalool predominates in *L. latifolia* EO (3.7–61.08%) (Table 8) and in *L. coronopifolia* from Jordan (20.77–41.16%) (Aburjai et al. 2005). Usually, in *L. stoechas*, the concentrations of linalool and linalyl acetate are very low or absent (Giray et al. 2008). However, a linalool/linalyl acetate chemotype (20.3/64.3%) has been described in *L. stoechas* populations from North Eastern Tunisia (Belhadj Mostefa et al. 2014). Linalool and linalyl acetate have also been identified as major components in *L. dentata* from Tunisia (47.3 and 28.7%, respectively) (Belhadj Mostefa et al. 2014; Msaada et al. 2012), and a chemotype linalool/linalyl acetate (50.1/7.3%) has been reported for Tunisian populations of *L. multifida* (Belhadj Mostefa et al. 2014; Messaoud et al. 2012). Linalool is present in low concentrations in Moroccan and Spanish populations of *L. dentata* (2–10%) (Belhadj Mostefa et al. 2014; Bousmaha et al. 2006), *L. viridis* (1.75–7.9%) (Costa et al. 2012; Zuzarte et al. 2011), *L. luisieri* (1.73–6.25%) (González-Coloma et al. 2011) and *L. gibsonii* J Graham (syn. *L. lawii* Wight syn. *L. perrottetii* Benth.) (2.65%) (Kulkarni et al. 2013).

The presence of larger amounts of linalool and linalyl acetate leads to a superior pharmaceutical and sensorial quality of true lavender EO (Duškova et al. 2016). Genuine true lavender oil contains an excess of enantiomers (R)-(-)-linalool (95.1–98.2%) and (R)-(-)-linalyl acetate (>99%) (Aprotosoaie et al. 2014). They are considered the most desired components of floral odour (Duškova et al. 2016). (R)-(-)-Linalool confers a floral woody lavender note while (R)-(-) linalyl acetate has a sweet green, bergamot, lavender, and woody aroma (Duškova et al. 2016). High values of linalool have been noted for the EOs obtained by hydrodistillation from dried *L. angustifolia* from Argentina (53.5%) (Martucci et al. 2015), USA (53.4%) (Renaud et al. 2001) and Australia (52.59%) (Danh et al. 2013) while large amounts of linalyl acetate have been reported for the essential oils obtained from English, French, and Australian true lavenders (52.2 and 50.3%, respectively) by head-space solid-phase microextraction (Se 2013). The highest level of linalyl acetate (56.7%) was found in the cultivar *Royal Velvet* (USA) that is highly aromatic cultivar of lavender and it was estimated to have the finest quality (Se 2013).

Also, French lavandin, mainly *Grosso* cultivar, contains high concentrations of linalool and linalyl acetate (45.51–47.51 and 45.1–48.2%, respectively) (Périno-Issartier et al. 2013; Se 2013). Similar levels of linalool have been identified in lavandin samples

Tabel 7 Overview of studies (2001–2016) on chemical composition of *L. x intermedia* EO

Main compounds	Plant material used for EO isolation	Concentration	References
Linalool	F	25.16–47.51% (France)	Périno-Issartier et al. (2013)
	FL	47.33% (Mauritius/var. *Grosso*)	Aumeeruddy-Elalfi et al. (2016)
	DP	34.1–47.3% (Spain/var. *Grosso*)	Carrasco et al. (2016)
	DP	39.4–45.8% (Spain/var. *Super*)	Carrasco et al. (2016)
	DF	42.24% (Macedonia)	Karapandzova et al. (2012)
	DF	41.9% (USA/var. *Grosso*)	Se (2013)
	DF	28.1–40.3% (France)	Se (2013)
	FF	40.13% (Macedonia)	Karapandzova et al. (2012)
	DF	38.5% (USA/var. *Super*)	Renaud et al. (2001)
	F	37.69% (Greece/var. *Special*)	Chatzopolou et al. (2003)
	DP	37% (Spain/var. *Abrial*)	Carrasco et al. (2016)
	FP	29.91–35.36% (Spain/var. *Super*)	Cerpa et al. (2008)
	FF	34% (Turkey)	Baydar (2009)
	F	24–33.6% (France)	Filly et al. (2016)
	DF	33.3% (USA/var. *Provence*)	Se (2013)
	NS	33.2% (Spain/var. *Super*)	Varona et al. (2013)
	FF	32.8% (Turkey)	Andoğan et al. (2002)
	NS	32.1% (Mexico/var. *Grosso*)	Flores et al. (2014)
	DF	31.1% (USA/var. *Abrial*)	Renaud et al. (2001)
	DF	29.1% (USA/var. *Provence*)	Renaud et al. (2001)
	DF	27.9% (USA/var. *Grosso*)	Renaud et al. (2001)
	FF	24.5% (Greece)	Papachristos et al. (2004)
	F	23.01% (Greece/var. *Super*)	Chatzopolou et al. (2003)
	NS	7.8% (Mexico/var. *Provence*)	Flores et al. (2014)
	FL	1.7% (Greece)	Papachristos et al. (2004)
Linalyl acetate	DF	18.2–48.2% (France)	Se (2013)
	FF	47.7% (Turkey)	Baydar (2009)
	FP	31.05–39.91% (Spain var. *Super*)	Cerpa et al. (2008)
	DF	37.5% (USA/var. *Grosso*)	Se (2013)
	DP	19.8–34.5% (Spain/var. *Super*)	Carrasco et al. (2016)
	DP	17.1–30.7% (Spain/var. *Grosso*)	Carrasco et al. (2016)
	F	11.3–30.1 (France)	Filly et al. (2016)
	FF	29.9% (Turkey)	Andoğan et al. (2002)
	NS	29.7% (Spain var. *Super*)	Varona et al. (2013)
	F	29.14% (Greece var. *Special*)	Chatzopolou et al. (2003)
	F	11.75–25.50% (France)	Périno-Issartier et al. (2013)
	NS	22.7% (Mexico var. *Grosso*)	Flores et al. (2014)
	F	20.35% (Greece var. *Super*)	Chatzopolou et al. (2003)
	DF	19.9% (USA/var. *Provence*)	Se (2013)
	DP	19.4% (Spain/var. *Abrial*)	Carrasco et al. (2016)
	DF	17.8% (USA/var. *Grosso*)	Renaud et al. (2001)
	DF	17.7% (USA/var. *Super*)	Renaud et al. (2001)
	DF	17.2% (USA/var. *Abrial*)	Renaud et al. (2001)
	FL	14.87% (Mauritius/var. *Grosso*)	Aumeeruddy-Elalfi et al. (2016)

Tabel 7 continued

Main compounds	Plant material used for EO isolation	Concentration	References
	DF	3.21% (Macedonia)	Karapandzova et al. (2012)
	DF	1.5% (USA/var. *Provence*)	Renaud et al. (2001)
1,8-Cineole	DL	31.64–47.94% (Iran)	Bajalan and Pirbalouti (2015)
	NS	46.5% (Mexico/var. *Provence*)	Flores et al. (2014)
	FL	42.1% (Greece)	Papachristos et al. (2004)
	FF	26.9% (Romania)	Jianu et al. (2013)
	DF	21.3% (USA/var. *Provence*)	Se (2013)
	DF	21.1% (USA/var. *Provence*)	Renaud et al. (2001)
	FF	19.3% (Greece)	Papachristos et al. (2004)
	F	15.85% (Greece/var. *Super*)	Chatzopolou et al. (2003)
	DF	10.7% (USA/var. *Grosso*)	Renaud et al. (2001)
	DF	3.8–9.3% (France)	Se (2013)
	DF	8.8% (USA/var. *Abrial*)	Renaud et al. (2001)
	DP	7.6% (Spain/var. *Abrial*)	Carrasco et al. (2016)
	NS	7.6% (Spain/var. *Super*)	Varona et al. (2013)
	NS	7.5% (Mexico/var. *Grosso*)	Flores et al. (2014)
	DF	7.5% (USA/var. *Grosso*)	Se (2013)
	FF	7.17% (Macedonia)	Karapandzova et al. (2012)
	DF	6.8% (USA/var. *Super*)	Renaud et al. (2001)
	DP	4.5–6.1% (Spain/var. *Grosso*)	Carrasco et al. (2016)
	F	3.5–5.6% (France)	Filly et al. (2016)
	F	5.39% (Greece/var. *Special*)	Chatzopolou et al. (2003)
	DP	3.9–4.8% (Spain/var. *Super*)	Carrasco et al. (2016)
	F	3.24–4.72% (France)	Périno-Issartier et al. (2013)
	FP	1.92–4.19% (Spain/var. *Super*)	Cerpa et al. (2008)
	DF	3.99% (Macedonia)	Karapandzova et al. (2012)
	FF	2.6% (Turkey)	Baydar (2009)
	FF	1.8% (Turkey)	Andoğan et al. (2002)
Camphor	FF	32.7% (Romania)	Jianu et al. (2013)
	FL	31.9% (Greece)	Papachristos et al. (2004)
	FF	16.8% (Greece)	Papachristos et al. (2004)
	DL	8.41–14.40% (Iran)	Bajalan and Pirbalouti (2015)
	NS	12.3% (Mexico/var. *Provence*)	Flores et al. (2014)
	F	11.35% (Greece/var. *Super*)	Chatzopolou et al. (2003)
	DP	9% (Spain/var. *Abrial*)	Carrasco et al. (2016)
	DF	2.2–8.8% (France)	Se (2013)
	F	7–8.3% (France)	Filly et al. (2016)
	DF	8.1% (USA/var. *Grosso*)	Renaud et al. (2001)
	DP	4.8–7.6% (Spain/var. *Super*)	Carrasco et al. (2016)
	DF	7.5% (USA/var. *Abrial*)	Renaud et al. (2001)
	DP	7.1% (Spain/var. *Grosso*)	Carrasco et al. (2016)
	NS	7.1% (Spain/var. *Super*)	Varona et al. (2013)
	NS	7.1% (Mexico/var. *Grosso*)	Flores et al. (2014)
	DF	7.04% (Macedonia)	Karapandzova et al. (2012)

Tabel 7 continued

Main compounds	Plant material used for EO isolation	Concentration	References
	FP	4.90–6.94% (Spain)	Cerpa et al. (2008)
	F	4.33–6.92% (France)	Périno-Issartier et al. (2013)
	FF	6.62% (Macedonia)	Karapandzova et al. (2012)
	DF	6.5% (USA/var. *Grosso*)	Se (2013)
	FL	5.54% (Mauritius)	Aumeeruddy-Elalfi et al. (2016)
	FF	5.3% (Turkey)	Andoğan et al. (2002)
	F	5.03% (Greece/var. *Special*)	Chatzopolou et al. (2003)
	FF	4.8% (Turkey)	Baydar (2009)
	DF	3.8% (USA/var. *Provence*)	Renaud et al. (2001)
	DF	3.5% (USA/var. *Super*)	Renaud et al. (2001)
	DF	2.3% (USA/var. *Provence*)	Se (2013)
Borneol	DL	17.11–26.14% (Iran)	Bajalan and Pirbalouti (2015)
	DF	16.68% (Macedonia)	Karapandzova et al. (2012)
	FF	13.71% (Macedonia)	Karapandzova et al. (2012)
	FF	7.11% (Romania)	Jianu et al. (2013)
	FL	6.7% (Greece)	Papachristos et al. (2004)
	FL	6.61% (Mauritius)	Aumeeruddy-Elalfi et al. (2016)
	FF	5% (Greece)	Papachristos et al. (2004)
	FF	4.2% (Turkey)	Baydar (2009)
	FP	3.66–5.49% (Spain)	Cerpa et al. (2008)
	F	1.5–4.5% (France)	Filly et al. (2016)
	DF	3.5–4% (France)	Se (2013)
	DP	2–3.9% (Spain/var. *Grosso*)	Carrasco et al. (2016)
	F	2.15–3.54% (France)	Périno-Issartier et al. (2013)
	NS	3.5% (Mexico/var. *Grosso*)	Flores et al. (2014)
	F	1.71% (Greece/var. *Special*)	Chatzopolou et al. (2003)
Terpinen-4-ol	DF	15.6% (USA/var. *Provence*)	Se (2013)
	F	6.67% (Greece var. *Super*)	Chatzopolou et al. (2003)
	FF	5.62% (Macedonia)	Karapandzova et al. (2012)
	DF	5.25% (Macedonia)	Karapandzova et al. (2012)
	F	4.2–5.2% (France)	Filly et al. (2016)
	DP	3–4.7% (Spain/var. *Grosso*)	Carrasco et al. (2016)
	DF	1.9–4.3% (France)	Se (2013)
	FL	3.72% (Mauritius/var. *Grosso*)	Aumeeruddy-Elalfi et al. (2016)
	DF	3.7% (USA/var. *Grosso*)	Se (2013)
	NS	3.3% (Spain)	Varona et al. (2013)
	NS	3.2% (Mexico var. *Grosso*)	Flores et al. (2014)
	F	1.61–1.82% (France)	Périno-Issartier et al. (2013)
Sabinene	FL	12.14% (Mauritius/var. *Grosso*)	Aumeeruddy-Elalfi et al. (2016)
α-Terpineol	F	4.7–10.2% (France)	Filly et al. (2016)
	FF	4.7% (Greece)	Papachristos et al. (2004)
	DF	1.8–4% (France)	Se (2013)
	F	3.81% (Greece var. *Super*)	Chatzopolou et al. (2003)

Tabel 7 continued

Main compounds	Plant material used for EO isolation	Concentration	References
	F	2.91% (Greece var. *Special*)	Chatzopolou et al. (2003)
	FF	2.8% (Turkey)	Andoğan et al. (2002)
Citronellol	FF	6.7% (Turkey)	Andoğan et al. (2002)
β-Pinene	NS	6.3% (Mexico var. *Provence*)	Flores et al. (2014)
	DL	0.84–2.59% (Iran)	Bajalan and Pirbalouti (2015)
trans-β-Ocimene	DP	6.1% (Spain var. *Abrial*)	Carrasco et al. (2016)
	F	2.08% (Greece var. *Special*)	Chatzopolou et al. (2003)
	DP	1.9–2% (Spain var. *Super*)	Carrasco et al. (2016)
	F	1.90% (Greece var. *Super*)	Chatzopolou et al. (2003)
Lavandulol	F	4.80–5.48% (France)	Périno-Issartier et al. (2013)
β-Caryophyllene	FF	4.88% (Romania)	Jianu et al. (2013)
	FP	2.28–3.12% (Spain)	Cerpa et al. (2008)
	F	2.2–2.3% (France)	Filly et al. (2016)
	DP	2% (Spain/var. *Abrial*)	Carrasco et al. (2016)
	DF	1.9% (USA/var. *Abrial*, *Grosso*)	Renaud et al. (2001)
cis-Linalool oxide	DF	1.6–4.2% (France)	Se (2013)
trans-Linalool oxide	DF	2.2–3.85 (France)	Se (2013)
	DF	3.6% (USA)	Se (2013)
Lavandulyl acetate	F	3.2–4.8% (France)	Filly et al. (2016)
	DF	3.1% (USA var. *Grosso*)	Renaud et al. (2001)
	DF	2.9% (USA var. *Abrial*)	Renaud et al. (2001)
	NS	2.6% (Spain)	Varona et al. (2013)
	DF	2.42% (Macedonia)	Karapandzova et al. (2012)
	DP	1.3–2.4% (Spain var. *Grosso*)	Carrasco et al. (2016)
	F	2.2% (Greece var. *Super*)	Chatzopolou et al. (2003)
	DF	2.2% (USA var. *Super*)	Renaud et al. (2001)
	F	1.75–2.16% (France)	Périno-Issartier et al. (2013)
β-Myrcene	DF	4% (USA/var. *Provence*)	Se (2013)
	DF	2% (USA/var. *Grosso*)	Se (2013)
β-Phellandrene	FF	3.87% (Romania)	Jianu et al. (2013)
	FF	3.64% (Macedonia)	Karapandzova et al. (2012)
α-Bisabolol	FF	4.16% (Romania)	Jianu et al. (2013)
	F	2.25–3.91% (France)	Périno-Issartier et al. (2013)
	F	2–3.1% (France)	Filly et al. (2016)

DA dried aerial parts, *DF* dried flowers, *DL* dried leaves, *DP* dried plants, *DS* dried stems, *F* flowers, *FF* fresh flowers, *FL* fresh leaves, *FP* fresh plants, *FS* fresh stems, *NS* nespecified

from Spain (45.8–47.3%) (Carrasco et al. 2016), Macedonia (40.13–42.24%) (Karapandzova et al. 2012), and USA (41.9%) (Se 2013). A high linalyl acetate content was also reported for Turkish (47.7%) (Baydar 2009) and Spanish flowers lavandin oils (39.91%) (Cerpa et al. 2008). Among lavandin cultivars, only *Super* cultivar is generally characterized by a higher linalyl acetate content (35–7%), its sensory profile being closer to that of *L. angustifolia* EO (Surburg and Panten 2006).

Table 8 Overview of studies on chemical composition of *Lavandula latifolia* EO

Main compounds	Plant material used for EO isolation	Concentration	References
Linalool	DF	3.7–61.08% (Spain)	Herraiz-Peñalver et al. (2013)
	DF	15.1–54.70% (Spain)	Muñoz-Bertomeu et al. (2007)
	DT	27.2–43.10% (Spain)	Salido et al. (2004)
	DA	32.6–35.8% (Spain)	Méndez-Tovar et al. (2015)
	DA	33.1% (Portugal)	Rodrigues et al. (2012)
	DF	32.3% (Tunisia)	Alatrache et al. (2007)
	FF	31.9% (Iran)	Barrazandeh (2002)
	DF	30.6% (Iran)	Barrazandeh (2002)
	DA	30.34% (Spain)	Méndez-Tovar et al. (2016)
	FF	30.3% (Spain)	De Pascual et al. (1989)
	DA	18.3–29.6% (Iran)	Eikani et al. (2006)
1,8-Cineole	DF	6.6–57.14% (Spain)	Herraiz-Peñalver et al. (2013)
	DL	45.4–54.6% (Spain)	Muñoz-Bertomeu et al. (2007)
	DF	20.8–47.9% (Spain)	Muñoz-Bertomeu et al. (2007)
	DA	41.96% (Spain)	Méndez-Tovar et al. (2016)
	DA	40.5% (Portugal)	Rodrigues et al. (2012)
	FF	36.3% (Spain)	De Pascual et al. (1989)
	DT	28–34.9% (Spain)	Salido et al. (2004)
	DA	11.8–22.8% (Iran)	Eikani et al. (2006)
	DF	20.9% (Iran)	Barrazandeh (2002)
	FF	18.8% (Iran)	Barrazandeh (2002)
	DF	11.7% (Tunisia)	Alatrache et al. (2007)
1,8-Cineole + Limonene	DA	37.4–42.6% (Spain)	Méndez-Tovar et al. (2015)
Camphor	DF	1.06–46.69% (Spain)	Herraiz-Peñalver et al. (2013)
	DL	31.5–43.5% (Spain)	Muñoz-Bertomeu et al. (2007)
	DT	10.8–23.2% (Spain)	Salido et al. (2004)
	DF	11.4–18.6% (Spain)	Muñoz-Bertomeu et al. (2007)
	DF	12.4% (Tunisia)	Alatrache et al. (2007)
	DA	9.27% (Spain)	Méndez-Tovar et al. (2016)
	DA	8.6–9% (Spain)	Méndez-Tovar et al. (2015)
	DA	8.17% (Portugal)	Rodrigues et al. (2012)
	DA	6.4–8% (Iran)	Eikani et al. (2006)
	FF	8% (Spain)	De Pascual et al. (1989)
Borneol	DA	14.2–19% (Iran)	Eikani et al. (2006)
	DF	8.9% (Iran)	Barrazandeh (2002)
	FF	10.1% (Iran)	Barrazandeh (2002)
	DF	0.16–5.93% (Spain)	Herraiz-Peñalver et al. (2013)
	DT	0.9–3.6% (Spain)	Salido et al. (2004)
	FF	2.8% (Spain)	De Pascual et al. (1989)
	DL	1.8–2.7% (Spain)	Muñoz-Bertomeu et al. (2007)
	DA	2.2–2.5% (Spain)	Méndez-Tovar et al. (2015)
	DA	0.9–1.8% (Spain)	Muñoz-Bertomeu et al. (2007)
α-Terpineol	DA	2.6–10.5% (Iran)	Eikani et al. (2006)
	FF	2.6% (Spain)	De Pascual et al. (1989)

Table 8 continued

Main compounds	Plant material used for EO isolation	Concentration	References
Lavandulol	DF	8.7% (Tunisia)	Alatrache et al. (2007)
Para-Cymen-8-ol	DF	7.7% (Tunisia)	Alatrache et al. (2007)
Terpinen-4-ol	DA	0.33–7.11% (Spain)	Herraiz-Peñalver et al. (2013)
	DA	1.4% (Iran)	Eikani et al. (2006)
Camphene	DA	0.24–5.3% (Spain)	Herraiz-Peñalver et al. (2013)
Linalyl acetate	DA	1.8–6.4% (Iran)	Eikani et al. (2006)
Farnesol	DF	0.04–4.99% (Spain)	Herraiz-Peñalver et al. (2013)
Bornyl acetate	DF	4.2% (Tunisia)	Alatrache et al. (2007)
9-Epi-β-Caryophyllene	DA	3.8% (Iran)	Herraiz-Peñalver et al. (2013)
β-Phellandrene	DF	0.18–3.74% (Spain)	Herraiz-Peñalver et al. (2013)

DA dried aerial parts, *DF* dried flowers, *DL* dried leaves, *DT* dried twigs, *FF* fresh flowers

Although *linalool/1,8-cineole/camphor* is the only chemotype described for spike lavender (Herraiz-Peñalver et al. 2013; Salido et al. 2004), the levels of linalool vary greatly being influenced by environmental factors, mainly in the Mediterranean region. Muñoz-Bertomeu et al. (2007) classified the essential oils obtained from Spanish wild populations of *L. latifolia* in high (42.5–54.7%), intermediate (31.4–36.4%), and low (15.1%) linalool content essential oils. Besides, Herraiz-Peñalver et al. (2013) described three ecotypes in Spanish wild populations of spike lavender including an ecotype characterized by its high linalool content (42.4%). It appears that, in general, Supra-Mediterranean bioclimatic belt promotes linalool-rich oil populations of Spanish spike lavender wild populations (42.5–54.7%) while most of the populations from Meso-Mediterranean bioclimatic belt show intermediate levels of linalool (Muñoz-Bertomeu et al. 2007).

The rainfall and subsequent temperature drop decrease the content of linalool in lavender flowers but concentration of linalyl acetate remains unaffected (Hassiotis et al. 2014). Also, plant ontogeny influences the accumulation of linalool and linalyl acetate in lavender. The content in monoterpenols and monoterpene esters increases with the opening of the first flowers. Once the first seeds matured, the monoterpenols become predominant (Guitton et al. 2010). *L.* × *intermedia* and *L. latifolia* species behave similar to *L. angustifolia* in relation to the accumulation of terpenes during inflorescence development while no change in essential oil composition was observed for *L. stoechas* plants (Guitton et al. 2010). It appears that the optimum harvest period to obtain valuable lavender EO is characterized by 60% flower blooming, temperature over 26 °C, and no precipitations ten days before harvesting (Hassiotis et al. 2014). Nature of plant material (flowers, leaves, and stems) also influences the chemical profile of lavender EOs. Low levels of linalool have been found in essential oils of true lavender leafy stems (1.8–5.76%) (González-Rivera et al. 2016; Adaszynska-Skwirzynska et al. 2014; Yazdani et al. 2013) or even linalool was absent in lavender leaf essential oils (Mantovani et al. 2013; Cassel et al. 2009). On the other hand, Aumeeruddy-Elalfi et al. (2016) reported large amounts of linalool in leaf essential oil of *Grosso* lavandin from Mauritius (47.33%). The compositional differences in the chemical profile of essential oils extracted from lavender floral and foliar tissues might be due to a different occurrence of secretory structures and dissimilar capabilities to biosynthesise and to accumulate volatile compounds as well as to the varying biochemical and physiological potentials of these plant organs for the utilization of growth resources (Hassanpouraghdam et al. 2011). The different ecological functions of monoterpenes in vegetative and reproductive tissues in the context of specific climatic conditions could be also responsible (Boeckelmann 2008).

1,8-Cineole and camphor

They are main components of *L. angustifolia* EO (0.31–44.4 and 1.9–28%, respectively), and usually predominate in the essential oils from lavenders leaves and stems (Table 6). Camphor is found mainly as dextrorotatory enantiomer (Carrasco et al. 2015b). High levels of 1,8-cineole and camphor diminish the quality of true lavender flowers essential oil providing harsher notes (Duškova et al. 2016). 1,8-Cineole has an aromatic camphor-like odour while camphor confers musty, penetrating, slightly minty notes (Bhowal and Gopal 2015; Ravid 2008). The investigation of *L. angustifolia* growing in North Africa revealed that Algerian essential oil is 1,8-cineole/camphor chemotype (37.8/24.6%) that is highly attractive for insecticidal use (Belhadj Mostefa et al. 2014). This chemotype is rather unusual for *L. angustifolia* since linalool and linalyl acetate are commonly reported in most of the studies. Also, flowers of Brazilian lavender contain high levels of 1,8-cineole (28.3%) (Maia et al. 2004). Usually, lavandin EOs have higher 1,8-cineole and camphor contents (1.8–47.94 and 2.2–32.70%, respectively) (Table 7) than lavender EOs resulting in a low quality of oils for the use in perfumery but valuable medicinal properties (Flores et al. 2014). *Provence* lavandin oils from Mexic and USA are extremely rich in 1,8-cineole (46.5 and 21.3%, respectively) (Flores et al. 2014; Se 2013). Also, high concentrations of 1,8-cineole and camphor have been reported for Romanian lavandin (26.9 and 32.7%, respectively) (Jianu et al. 2013). With regard to the essential oils from lavandin leaves, 1,8-cineole, camphor are the main compounds. 1,8-Cineole has been found in large concentrations in Iranian lavandin (47.94%) (Bajalan and Pirbalouti 2015), while 1,8-cineole and camphor predominate in Greek lavandin (42.10 and 31.90%, respectively) (Papachristos et al. 2004). Flores et al. (2014) showed that the impact of the geographical region led to a fivefold higher level of 1,8-cineole and a twofold higher level of camphor in *Provence* lavandin cultivated in Mexic compared with lavandin grown in France.

1,8-Cineole and camphor are the major compounds in *L. latifolia* EOs (6.60–57.14 and 1.06–46.69%, respectively) (Table 8). Garciá Vallejo (1992) reports even higher values of 1,8-cineole in *L. latifolia* from Spain (8.8–71.5%). For Spanish spike lavender wild populations, an inverse variation regarding the levels of 1,8-cineole, camphor and linalool was described. Low levels of camphor (11.4–13.4%) have been identified in the linalool-rich populations while a high 1,8-cineole content (47.9%) occurs in linalool-poor populations (Muñoz-Bertomeu et al. 2007). In addition, Herraiz-Peñalver et al. (2013) described an ecotype of *L. latifolia* in Spanish wild populations, characterized by its high content in camphor (20%).

1,8-Cineole and camphor are some of the most abundant compounds in *L. viridis* (7.81–74 and 2.9–31.59%, respectively) (Costa et al. 2012; Zuzarte et al. 2011; Gonçalves et al. 2008; Nogueira and Romano 2002), *L. pedunculata* (2.4–55.5 and 3.6–48%, respectively) (Costa et al. 2013), and *L.* × *heterophylla* (Sweet lavender) (50.13 and 20.38%, respectively) (Kim and Lee 2002). Besides, 1,8-cineole has been identified as main component in samples of *L. dentata* from Spain (39–67%), Algeria (18.3–48%), Morocco (5.53–32%) (Imelouane et al. 2010; Bousmaha et al. 2006), and Korea (47.02%) (Kim and Lee 2002), and in *L. coronopifolia* from Jordan (7.31–25.43%) (Aburjai et al. 2005). Furthermore, a chemotype 1,8-cineole/β-pinene (48/6.1%) was described for Algerian *L. dentata* (Bousmaha et al. 2006).

Camphor occurs in high amounts in samples of Spanish *L. pedunculata* subsp. *sampaiana* (4.3–84.4%) (Garciá Vallejo 1992), wild populations of *L. luisieri* (74.4%) (Julio et al. 2014), *L. dentata* from Morocco (50–72%) and Saudi Arabia (54.6%) (Belhadj Mostefa et al. 2014; Msaada et al. 2012), *L. lanata* (43–59%) (Lis-Balchin 2012), *L. stoechas* (1.94–56.20%) (Table 9) but also in Spanish populations of *L. luisieri* (1.8–53.7%) (González-Coloma et al. 2006), *L. canariensis* from Greece (51.8%) (Tzakou et al. 2009) and Portuguese populations of *L. pedunculata* subp. *lusitanica* (40.6%) (Costa et al. 2013). For *L. stoechas*, the Greek, Korean and Turkish populations are extremely rich in camphor (over 50%) while 1,8-cineole is consistently present in Greek and Turkish populations (24.5–34.4 and 20.29%, respectively) (Table 9). Besides, a 1,8-cineole/camphor chemotype has been reported for Turkish populations of *L. stoechas* (Benabdelkader et al. 2011). In addition, a high content of 1,8-cineole has been found in populations from northern shores of the Mediterranean Sea and North Africa (more than 8%) (Benabdelkader et al. 2011). One of the main chemotypes described for *L. pedunculata* is characterized by the presence of 1,8-cineole where two subgroups differentiate themselves depending on the concentration of 1,8-cineole and camphor: 1.8-cineole and 1,8-cineole/camphor subgroups (Costa et al. 2013). The essential oils obtained from in vitro shoot-cultures and micropropagated

Table 9 Overview of studies on chemical composition of *Lavandula stoechas* EO

Main compounds	Plant material used for EO isolation	Concentration	References
Fenchone	NS	14.9–75.5% (France-Corsica)	Ristorcelli et al. (1998)
	DF	72.97% (Italy-Sardinia)	Angioni et al. (2006)
	DL	68.2% (Tunisia)	Bouzouita et al. (2005)
	DA	27.56–64.03% (Turkey)	Kaya et al. (2012)
	DA	45.29–60.27% (Italy)	La Bella et al. (2015)
	DL	59.48% (Italy)	Angioni et al. (2006)
	DF	10.4–56.33% (Greece)	Skoula et al. (1996)
	DL	18.7–48.9% (Greece)	Skoula et al. (1996)
	FA	45.19% (Greece)	Hassiotis (2010)
	DL	41.9% (Turkey)	Kirmizibekmez et al. (2009)
	F	39.9% (Greece)	Tzakou et al. (2009)
	DF	39.2% (Turkey)	Kirmizibekmez et al. (2009)
	DA	37% (Italy)	Zuzarte et al. (2013)
	NS	33.6–37% (Spain)	Carrasco et al. (2015b)
	F	26.93–34.23% (Turkey)	Giray et al. (2008)
	DA	30.5% (Morocco)	Zrira and Benjilali (2003)
	DA	11.27–37.48% (Algeria)	Benabdelkader et al. (2011)
	DA	24.30% (Korea)	Kim and Lee (2002)
	FL	21.9% (France)	Paolini et al. (2008)
	L	21% (Greece)	Tzakou et al. (2009)
	DA	3.06% (Morocco)	Cherrat et al. (2014)
Camphor	NS	2.5–56.2% (France-Corsica)	Ristorcelli et al. (1998)
	DA	53.40% (Korea)	Kim and Lee (2002)
	DA	16.73–50.94% (Turkey)	Kaya et al. (2012)
	F	14.71–41.09% (Turkey)	Giray et al. (2008)
	DA	1.6–36% (Greece)	Skoula et al. (1996)
	DA	27.3% (Italy)	Zuzarte et al. (2013)
	FL	26.9% (France)	Paolini et al. (2008)
	L	26.3% (Greece)	Tzakou et al. (2009)
	F	24.2% (Greece)	Tzakou et al. (2009)
	NS	15.6–24.1% (Spain)	Carrasco et al. (2015b)
	DA	7.94–20.15% (Italy)	La Bella et al. (2015)
	DA	1.94–21.80% (Algeria)	Benabdelkader et al. (2011)
	DA	18.2% (Morocco)	Zrira and Benjilali (2003)
	DL	15.36% (Italy)	Angioni et al. (2006)
	DL	12.1% (Turkey)	Kirmizibekmez et al. (2009)
	DL	11.2% (Tunisia)	Bouzouita et al. (2005)
	FA	9.90% (Greece)	Hassiotis (2010)
	DF	9.25% (Italy-Sardinia)	Angioni et al. (2006)
	DF	5.9% (Turkey)	Kirmizibekmez et al. (2009)
Pulegone	L	40.4% (Turkey)	Gören et al. (2002)
1,8-Cineole	DL	0.1–34.4% (Greece)	Skoula et al. (1996)
	DF	0.1–24.5% (Greece)	Skoula et al. (1996)
	DA	1.80–20.29% (Turkey)	Kaya et al. (2012)

Table 9 continued

Main compounds	Plant material used for EO isolation	Concentration	References
	NS	17.8% (France-Corsica)	Ristorcelli et al. (1998)
	NS	17.2–18% (Spain)	Carrasco et al. (2015b)
	DA	0.13–16.31% (Italy)	La Bella et al. (2015)
	FA	16.30% (Greece)	Hassiotis (2010)
	DL	15.6% (Turkey)	Kirmizibekmez et al. (2009)
	DA	12.50% (Korea)	Kim and Lee (2002)
	FL	8.8% (France)	Paolini et al. (2008)
	DA	8.6% (Morocco)	Zrira and Benjilali (2003)
	DA	0.16–8.71% (Algeria)	Benabdelkader et al. (2011)
	F	3.06–7.67% (Turkey)	Giray et al. (2008)
	DA	6% (Italy)	Zuzarte et al. (2013)
	L	3.9% (Turkey)	Gören et al. (2002)
10 s, 11 s-Himachala-3 (12), 4-diene	DA	23.62% (Morocco)	Cherrat et al. (2014)
Myrtenyl acetate	DF	3.2–24.1% (Greece)	Skoula et al. (1996)
	F	1.66–11.70% (Turkey)	Giray et al. (2008)
	DA	9.5% (Turkey)	Kirmizibekmez et al. (2009)
	L	0.19–8.45% (Turkey)	Kaya et al. (2012)
	DL	0.5–6.1% (Greece)	Skoula et al. (1996)
	DL	5.02% (Italy)	Angioni et al. (2006)
	DA	4.96% (Morocco)	Cherrat et al. (2014)
	DF	3.69% (Italy-Sardinia)	Angioni et al. (2006)
	DL	1.9% (Turkey)	Kirmizibekmez et al. (2009)
Menthol	L	18.1% (Turkey)	Gören et al. (2002)
Cubenol	DA	16.19% (Morocco)	Cherrat et al. (2014)
α-Pinene	DF	1.8–14.2 (Greece)	Skoula et al. (1996)
	DA	0.13–5.56% (Turkey)	Kaya et al. (2012)
	FL	4.9% (France)	Paolini et al. (2008)
	NS	2.3–4.5% (Spain)	Carrasco et al. (2015b)
	DL	0.5–3.4% (Greece)	Skoula et al. (1996)
	NS	0.9–1.4% (France)	Ristorcelli et al. (1998)
Menthone	L	12.6% (Turkey)	Gören et al. (2002)
Camphene	NS	0.5–7.7% (France-Corsica)	Ristorcelli et al. (1998)
	FL	7% (France)	Paolini et al. (2008)
	DA	3.5% (Morocco)	Zrira and Benjilali (2003)
	DL	2.75% (Italy)	Angioni et al. (2006)
	DA	2.30% (Korea)	Kim and Lee (2002)
Viridiflorol	DA	2.89–7.38% (Algeria)	Benabdelkader et al. (2011)
	DA	4% (Turkey)	Kirmizibekmez et al. (2009)
	DA	2.6% (Italy)	Zuzarte et al. (2013)
α-Cadinol	DA	0.1–7.7% (Greece)	Skoula et al. (1996)
	FA	4.2% (Greece)	Hassiotis (2010)
Methyleugenol	DA	6.19% (Morocco)	Cherrat et al. (2014)

Table 9 continued

Main compounds	Plant material used for EO isolation	Concentration	References
Bornyl acetate	DA	6.2% (Italy)	Zuzarte et al. (2013)
	NS	5.7% (France-Corsica)	Ristorcelli et al. (1998)
	DF	5.10% (Italy-Sardinia)	Angioni et al. (2006)
	DA	0.46–4% (Algeria)	Benabdelkader et al. (2011)
	FL	3.8% (France)	Paolini et al. (2008)
	DA	1.14% (Korea)	Kim and Lee (2002)
δ-Cadinene	DA	5.31% (Morocco)	Cherrat et al. (2014)
Linalool	NS	5.2% (France-Corsica)	Ristorcelli et al. (1998)
	DF	2.1% (Turkey)	Kirmizibekmez et al. (2009)

DA dried aerial parts, *DF* dried flowers, *DL* dried leaves, *F* flowers, *FA* fresh aerial parts, *FF* fresh flowers, *FL* fresh leaves, *L* leaves, *NS* nespecified

Portuguese plants of *L. viridis* contain also, as major components, 1,8-cineole (18.2–51.3%) and camphor (9.1–15.3%) (Gonçalves et al. 2008; Nogueira and Romano 2002). A low level of camphor has been identified in *L. bipinnata* (Roth) Kuntze syn. *L. burmanni* Benth (7.09%) (Hanamanthagouda et al. 2010).

The content of camphor and 1,8-cineole in lavenders is influenced by both developmental and environmental factors (Hassiotis et al. 2014). These monoterpenoids are mostly found in both immature flowers and leaves. The 1,8-cineole concentration increases after rainfall and subsequent temperature drop (Hassiotis et al. 2014) and Thermo-Mediterranean bioclimatic belt favors 1,8-cineole accumulation (Muñoz-Bertomeu et al. 2007). In addition, lower altitudes (below 500 m above sea level) seemed to favor the biosynthesis of camphor (Herraiz-Peñalver et al. 2013). Also, it appears that a low camphor content correlates with a high β-carryophyllene sesquiterpene level (Carrasco et al. 2016).

Fenchone

This monoterpenketone was detected as major compound in *Lavandula stoechas* EOs (3.06–75.50%), where it occurs as dextrorotatory enantiomer (Table 9). The fenchone/camphor chemotype is the most commonly reported for *L. stoechas* plants. It has been identified for the plants from Algeria, Cyprus, France (Corsica), Greece (Crete), Italy, Morocco, Turkey, Tunisia (Benabdelkader et al. 2011). The ratio between fenchone and camphor may vary highly and may be even reversed in the Mediterranean populations from a restricted geographic area. A similar finding has been reported for *L. stoechas* from Korea (camphor 53.40%/fenchone 24.30%) (Kim and Lee 2002). A fenchone/1,8-cineole chemotype has been described for some populations from Greece (Crete), Italy (Sicily), and Spain growing in the same phytogeographic area as others with fenchone/camphor chemotype (Tuttolomondo et al. 2015; Benabdelkader et al. 2011). Although *L. pedunculata* is morphologically distinct from *L. stoechas,* its essential oil contains also fenchone as the major component (1.3–59.7%). Even a chemotype characterized by the presence of fenchone was reported. Also, essential oil of Portuguese *L. pedunculata* subp. *lusitanica* displays a composition rich in fenchone (38%) (Costa et al. 2013). Portuguese and Spanish populations of *L. luisieri* contain significant amounts of fenchone (1.35–36.77 and 1.4–22%), and higher values have been found in the flower essential oils (González-Coloma et al. 2006). Although fenchone is not a characteristic compound of *L. angustifolia*, it has been reported as major compound in the flower essential oil of Egyptian true lavender (16.79%) (Tarek et al. 2014) and in leaf essential oil of Brazilian true lavender (14.9%) (Cassel et al. 2009).

Borneol

It has been identified as main component in true lavender (1.4–24%) (Table 6), lavandin (1.71–26.14%) (Table 7) and spike lavender EOs (0.9–19%) (Table 8), being present in larger amounts in the essential oils from leaves and aerial parts than in lavender flowers EOs. Borneol occurs as dextrorotatory enantiomer in lavandin (Carrasco et al. 2016) while a predominance of levorotatory enantiomers was described for *L. stoechas* (Carrasco et al. 2015b). Regardless of species (*L. angustifolia*, *L.*× *intermedia* or *L. latifolia*), Iranian lavender EOs are particularly rich in borneol (8.9–26.14%) (Tables 6, 7, 8). An unusual high level of borneol has been found in Moroccan *L. dentata* (47%) (Belhadj Mostefa et al. 2014). The accumulation of borneol as well as of its ester (bornyl acetate) are influenced by lavender plants ontogeny, and they are mostly found in both immature flowers and leaves (Hassiotis et al. 2014).

Terpinen-4-ol and α-*Terpineol*

These monoterpenols are abundant in essential oils of *L. angustifolia* (2–14.01 and 2–9.17%, respectively) (Table 6), *L.* × *intermedia* (1.61–15.6 and 2.8–10.2%, respectively) (Table 7), and *L. latifolia* (0.33–7.11 and 2.6–10.5%, respectively) (Table 8). Also, high values of terpinen-4-ol have been reported for *L. coronopifolia* from Jordan (4.43–10.97%) while the level of α-terpineol is low (about 1%) (Aburjai et al. 2005). The essential oils from in vitro shoot-cultures and micropogated plants of *L. viridis* contain α-terpineol as main component (2.7 and 4.2%, respectively) (Nogueira and Romano 2002). Terpineol-4 and α-terpineol are minor components in *L. stoechas* (values below 1%) (Hassiotis 2010; Giray et al. 2008; Bouzouita et al. 2005; Skoula et al. 1996). The chiral characterization of lavender and lavandin EOs showed that (4S)(+)-terpineol-4 and (4R)(+)-α-terpineol are predominant enantiomers (Carrasco et al. 2016; Ravid 2008) while in *L. stoechas* these compounds occur as levorotatory enantiomers (Carrasco et al. 2015b). The content in terpinen-4-ol increases with the opening of the first lavender flowers and reaches the highest values once the first seeds matured. Also, in *L. latifolia*, the levels of terpinen-4-ol are higher in faded inflorescens (Guitton et al. 2010). The rainfall and temperature drop increase the concentration of terpinen-4-ol (Hassiotis et al. 2014).

Lavandulol and lavandulyl acetate

L. lanata (wooly lavender) has variable amounts of lavandulol (3–27%) (Lis-Balchin 2012). Some Spanish cultivars of *L. lanata* are extremely rich in lavandulol (over 35%) being valuable in perfumery (Barrero et al. 2008). Tunisian *L. latifolia* also contains high concentrations of lavandulol (8.7%) (Alatrache et al. 2007). The intermediate levels have been noted in *L. angustifolia* and *L.*× *intermedia* (2.1–4.3 and 4.80–5.48%, respectively) (Tables 6 and 7). The significant presence of lavandulyl acetate has been reported in *L. angustifolia* (1.2–15.9%) (Table 6), Portuguese populations of *L. luisieri* (2.2–7.1%) (Zuzarte et al. 2012a), *L.*× *intermedia* (1.75–4.8%) (Table 7), Spanish populations of *L. stoechas* (3.5%) (Carrasco et al. 2015b) and *L. pedunculata* from Portugal (3.2%) (Zuzarte et al. 2010). Iranian and Chinese true lavender oils are particularly rich in lavandulyl acetate (over 10%) (Table 6). The level of lavandulyl acetate increases with the opening of the first lavender flowers (Guitton et al. 2010).

Other monoterpenoids

The monoterpene ketones pulegone (8.45%) and piperitone (4.65%), and monoterpenols *trans*-carveol (18.93%) and menthol (5.89%) are the major components of the *L. bipinnata* (Roth) Kuntze (syn. *L. burmanni* Benth) leaf essential oil (Hanamanthagouda et al. 2010). Also, high concentrations of *trans*-pinocarveol have been identified in samples of *L. dentata* from Morocco (8.6–14.8%), Spain (5.8–9.8%) (Belhadj Mostefa et al. 2014; Bousmaha et al. 2006) and Yemen (7.5%) (Mothana et al. 2012). Besides, *L. dentata* from Morocco contains large amounts of monoterpene aldehyde, myrtenal (6.8–8.8%) (Imelouane et al. 2010). Myrtenyl acetate (0.19–24.10%), a monoterpene-ester with floral, violet-like, fruity and herbaceous fragrance, is one of the main compounds of *L. stoechas* EOs (Table 9). For Turkish leaf essential oil of *L. stoechas,* Gören et al. (2002) have reported a peculiar chemotype pulegone/menthol (40.4/18.1%). Verbenone (3.54–12.14%) is one of the major components of *L. viridis* EOs (Costa et al. 2012; Zuzarte et al. 2011; Gonçalves et al. 2008; Nogueira and Romano 2002). An unusual high content of geraniol has been noted for *L. angustifolia* from China (11.02%) (Cong et al. 2008) while a significant presence of geranyl acetate was detected in *L. luisieri* (14.2%) (Julio et al. 2014).

Phenolic terpenoids

The essential oil of *L. pubescens* from Yemen (Al-Badani et al. 2016; Chhetri et al. 2015) and Saudi Arabia (Al-Sarar 2014) contains high levels of carvacrol (20.6–77.5 and 85.3%, respectively). Carvacrol methyl ether (3.45–11.39%) is another major compound in plants from Yemen (Al-Badani et al. 2016). The main components of *L. multifida* are monoterpene phenols carvacrol (21.14–66.2%) and thymol (32%), unusual for lavender oils (Saadi et al. 2016; Belhadj Mostefa et al. 2014; Sellam et al. 2013; Chograni et al. 2012), and *para*-cymene (15.7%) (Belhadj Mostefa et al. 2014). Also, an another phenol, durenol (2,3,5,6-tetramethylphenol), was the most abundant compound in the Morrocan *L. multifida* (89.97%) (N'Dédianhoua Soro et al. 2014). For Portuguese populations, a chemotype carvacrol/*cis*-ocimene (42.8/27.4%) has been identified (Zuzarte et al. 2012b), and for the Tunisian populations, a chemotype carvacrol/β-bisabolene (65.1/24.7%) has been reported (Belhadj Mostefa et al. 2014; Messaoud et al. 2012). Carvacrol (23.6–42.6%) and bisabolene sesquiterpene (7.5–20.8%) were also reported as the predominant compounds in the essential oil from the leaves of *L. canariensis* (Palá-Paúl et al. 2004). A carvacrol/β-bisabolene chemotype has been identified for Tunisian populations of *L. coronopifolia* (18.5/13.1%) (Belhadj Mostefa et al. 2014). *L. coronopifolia* from Jordan contains both carvacrol and thymol but their levels are low (2.12 and 1.45%) (Aburjai et al. 2005). Carvacrol and its methyl ether have also been found as main components in *L. pinnata* L. f. (syn. *L. pinnata* Lundmark) (Argentieri et al. 2016) and thymol (10.42%) has been detected in the essential oil extracted from the aerial parts of *L. gibsonii* (Kulkarni et al. 2013). Leaf essential oil from Algerian *L. multifida* contains anethole (17.37%) as major component (Saadi et al. 2016). Although monoterpene phenols are atypical compounds for *L. angustifolia*, in some Italian true lavender EOs, carvacrol (0.76–1.54%) has been identified as minor component (Binello et al. 2014). Cumin aldehyde (2.2%), an aromatic aldehyde, has been detected in leaf essential oils from Iranian lavender (Hassanpouraghdam et al. 2011). Another aromatic aldehyde with sweet rose, honey and green odour, phenylacetaldehyde, is the main component of leaf essential oil of *L. pinnata* L. fil. var. *pinnata* from Madeira (6–9%) (Figueiredo et al. 1995).

Irregular monoterpenoids

The essential oil of *L. luisieri*, a small aromatic shrub endemic to the Iberian Peninsula, has an atypical composition, and distinct from other *Lavandula* species due to the presence of 1,2,2,3,4-pentamethylcyclopentane (necrodane) derivatives, a category of irregular monoterpenoids with cyclopentanic structures. Garciá Vallejo (1992) was the first to identify these compounds and later, other authors have reported a variety of compounds with a necrodane structure in *L. luisieri* essential oils. These derivatives were found only in the defensive secretion of the beetle, *Necrodes surinamensis*, suggesting a potential role of these compounds in plant defense (Pombal et al. 2016; Julio et al. 2014). The most important components of *L. luisieri* populations from Spain are 2,3,4,4-tetramethyl-5-methylen-2-cyclopenten-1-one (5.8–38.3%), while *trans*-α-necrodyl acetate and *cis*-α-necrodyl acetate were minor components (less than 5%) (González-Coloma et al. 2006). On the contrary, *trans*-α-necrodyl acetate (3.2–48.22%) and *trans*-α-necrodol (0.40–11.51%) are major compounds in Portuguese populations (Zuzarte et al. 2012a; González-Coloma et al. 2011). These compounds occur in larger amounts in the leaf essential oils than in flowers. Also, cultivated populations have a wide spectrum and high levels of irregular monoterpenoids than wild populations: *trans*-α-necrodyl acetate (33%), *trans*-α-necrodol (7.7%), *cis*-α-necrodyl acetate (5.9%), *cis*-α-necrodol (3.3%) compared to *trans*-α-necrodyl acetate (8.2%) (Julio et al. 2014). α-Necrodyl acetate has also been found in Algerian *L. stoechas* (Benabdelkader et al. 2011). Another irregular monoterpene, cryptone (3.5%) has been identified in leaf essential oils from Iranian true lavender (Hassanpouraghdam et al. 2011).

Monoterpene hydrocarbons

They are generally considered minor constituents of lavender EOs. Both immature lavender flowers and leaves mostly accumulate monoterpenes (Guitton et al. 2010). The highest levels of monoterpene hydrocarbons are found in *L. dentata* (4.7–20% and for some samples, even over 40%), *L. angustifolia* (1.5–32.7%), *L. pedunculata* (4.5–24.8%), and *L.* × *intermedia* (1.1–17.17%). The lavender monoterpenes are mainly represented by acyclic (β-myrcene, *cis*- and *trans*-ocimene), monocyclic (D-limonene), and bicyclic structures (α-, β-pinene and camphene). Some of them, such as: α-pinene, β-pinene, limonene, and 3-carene predominate as dextrorotatory enantiomers while camphene is primarily found as levorotatory enantiomer (Carrasco et al. 2015b, 2016). The hydrodistilled essential oils from some true lavender native Greek populations and *L. angustifolia* var. *Etherio* are characterized by high content of monoterpenes (32.70 and 21%, respectively) (Hassiotis et al. 2010) while Iranian lavender EO obtained by hydrodistillation-headspace solvent microextraction has a low level of hydrocarbons (1.5%) (Fakhari et al. 2005). Monoterpene hydrocarbons do not contribute much to the aroma of essential oils; they tend to oxidize with a consequent degradation of odour so that the use of lavender oils as flavor agents in food industry and perfumery requires the removal of some monoterpenes as limonene (Da Porto et al. 2009; Giray et al. 2008).

α- and β-Pinene

β-Pinene has been found as predominant compound in samples of *L. dentata* from Spain (27.5–42.4%) and Morocco (27.1–30.1%), alongside with α-pinene (9.6–13.2 and 7.8–8.4%, respectively) (Belhadj Mostefa et al. 2014; Bousmaha et al. 2006). Also, Algerian *L. dentata* contains high levels of β-pinene (6.1–12.4%) (Bousmaha et al. 2006). A consistent presence of α-pinene has been detected in Greek *L. stoechas* (14.2%) (Skoula et al. 1996) and Portuguese *L. viridis* (9–10.3%) (Zuzarte et al. 2011; Nogueira and Romano 2002). α-Pinene (8–14.4%) and β-pinene (2.6–4%) were also identified as major constituents in the essential oil obtained from in vitro shoot-cultures and micropropagated Portuguese plants of *L. viridis* (Gonçalves et al. 2008; Nogueira and Romano 2002). The intermediate levels of pinenes occur in samples of *L. angustifolia* from Romania (4.27–6.63%) (Călinescu et al. 2014) and *L.* × *intermedia* from Mexico/var. *Provence* (6.3%) (Flores et al. 2014).

α-Terpinolene

It is the major component in the essential oils extracted from *L. gibsonii* (22.22%) (Kulkarni et al. 2013) and *L. pubescens* (0.6–9.2%) (Al-Badani et al. 2016).

Cis-β- and *trans*-β-Ocimene

cis-Ocimene is abundant in *L. multifida* (27–27.4%) (Zuzarte et al. 2012b). Even a chemotype carvacrol/*cis*-ocimene was identified for this species (data presented at phenolic terpenoids section) (Zuzarte et al. 2012b). Also, *L. coronopifolia* contains significant levels of *trans*-β-ocimene (26.9%) (Messaoud et al. 2012). *Cis*-β- and *trans*-β-ocimene are some of the most important compounds in Bulgarian *L. angustifolia* (18.4 and 13%, respectively) (Milina et al. 2012), and *trans*-β-ocimene is the major component in Spanish lavandin/var. *Abrial* (6.1%) (Carrasco et al. 2016).

Other monoterpenes

Sabinene is the main compound in Morrocan *L. dentata* (13.89%) (Imelouane et al. 2010) and *L.* × *intermedia* (12.14%) (Aumeeruddy-Elalfi et al. 2016), γ-terpinene in *L. multifida* (9.5%) (Belhadj Mostefa et al. 2014), and myrcene, in *L. coronopifolia* EO (7.5%) (Messaoud et al. 2012). Earlier studies on *L. pinnata* L. fil. var. *pinnata* from Madeira showed that the most abundant compounds in flower essential oil were β-phellandrene (12–32%) and α-phellandrene (6–16%) (Figueiredo et al. 1995). High values of β-phellandrene have also been noted for *L. angustifolia* (16%) and lavandin (3.87%) from Romania (Jianu et al. 2013). Spanish spike lavender contains important amounts of β-phellandrene (3.74%) (Herraiz-Peñalver et al. 2013) while α-phellandrene is main compound in Brazilian lavander (5.7%) (Maia et al. 2004).

Sesquiterpenes

As in the case of monoterpenes, the sesquiterpenes (both hydrocarbons and oxygenated derivatives) represent minor compounds in lavender EOs, likely coupled with a weak activity of MVA pathway, the main route of their biosynthesis (Lane et al. 2010). The richest species are *L. canariensis* (about 40%), *L. angustifolia* (1.2–38.40%), *L. stoechas* (2.6–28.08%) and *L. luisieri* (3.34–23.05%). The main sesquiterpenes reported in lavender EOs are β-caryophyllene, β-farnesene, bisabolene, germacrene D, α-muurolol, α-bisabolol, α-cadinol, caryophyllene oxide, and viridiflorol.

β-caryophyllene is typically found in concentrations below 6% but *L. angustifolia* from Romania, *L. pinnata* L. fil. var. *pinnata* from Madeira and Australian *L. canariensis* contain unusual high levels of this compound (24.12, 11, and 7.6%, respectively) (Jianu et al. 2013; Palá-Paúl et al. 2004; Figueiredo et al. 1995). Caryophyllene oxide is one of the major compounds in leafy stems essential oils from Polish varieties of true lavender (7.98–8.68%) (Adaszynska-Skwirzynska et al. 2014), *L. pubescens* (2.1–6.9%) (Al-Badani et al. 2016), and *L. dentata* (3.1%) (Mothana et al. 2012). The sesquiterpenes 10 s, 11 s-himachala-3 (12), 4-diene (23.62%) and cubenol (16.19%) predominate in some Morrocan populations of *L. stoechas* (Cherrat et al. 2014). Bisabolene was reported as the main compound in the essential oils of *L. multifida* (1–24.7%) (Saadi et al. 2016; Belhadj Mostefa et al. 2014; Chograni et al. 2010), *L. canariensis* Mill. (7.5–20.8%) (Palá-Paúl et al. 2004), *L. coronopifolia* (13.1%) (Belhadj Mostefa et al. 2014) and *L. pubescens* (2.5%) (Nasser et al. 2013). β-Selinene (9.31–12.82%) and viridiflorol (1.38–12.1%) are the characteristic sesquiterpenes in Portuguese populations of *L. luisieri* (González-Coloma et al. 2006, 2011). Also, β-selinene has been identified in *L. dentata* from Yemen (4.5%) (Mothana et al. 2012), and high concentrations of viridiflorol occur in Algerian *L. stoechas* (2.89–7.38%) (Benabdelkader et al. 2011). *L. angustifolia* and *L.* × *intermedia* are important sources of α-bisabolol (2.31–14.1 and 2–4.16%, respectively) (Tables 6, 7), the leaf essential oils being richer in bisabolol than those from flowers.

Other major sesquiterpenes in lavender EOs are: spathulenol (*L. pinnata* L. f.-12.22%; *L. multifida*-4.9%) (Argentieri et al. 2016; Sellam et al. 2013), farnesene (*L. canariensis*-11.3%) (Palá-Paúl et al. 2004), α-cadinol (*L. stoechas*-7.7%; *L. pedunculata*-4%) (Zuzarte et al. 2010; Skoula et al. 1996), δ-cadinene (*L. stoechas*-5.31%) (Cherrat et al. 2014), and β-copaene (*L. pubescens*-3.7%) (Nasser et al. 2013).

Coumarins

In some Italian lavender EOs, atypical components such as coumarins (coumarin, 7-methoxycoumarin) (over 20%) have been identified (Binello et al. 2014). The presence of coumarins might be explained by the use of leaves for EO extraction (coumarins are typical constituents of lavender foliar tissues) or by the technique of extraction.

Influence of extraction methods on the chemical composition and aroma of lavender essential oils

Conventional extraction methods, hydrodistillation (HD) and steam distillation, have been frequently used to isolate lavender essential oils, with large variations of distillation time (30 min–5 h). Solvent extraction or green extraction methods (microwave assisted extraction, supercritical fluid extraction, ultrasound assisted extraction, or different combined configurations such as microwave-assisted hydrodistillation, microwave-steam distillation, microwave-assisted gravity hydrodiffusion, and coaxial microwave-assisted hydrodistillation) have been used to a less extent, although they show some advantages (industrial scale-up, different product selectivity, energy and time savings, low environmental impact) (González-Rivera et al. 2016).

The distillation conditions (aqueous medium, pH, high temperatures, prolonged extraction) may affect the chemical composition of the essential oils, causing loss of volatile components, thermal or hydrolytic degradation of unsaturated compounds or esters, changes of odorant profile, and possible toxic residual solvents in oil (Périno-Issartier et al. 2013). Hydrodistillation can lead to a degradation of thermolabile compounds and hydrolysis of water-sensitive compounds at acidic pH (5.5–6.5). During hydrodistillation, linalyl acetate partly degrades, resulting in higher linalool content compared with steam distillation (Périno-Issartier et al. 2013). Degradation of esters (linalyl acetate) during hydrodistillation may also increase the levels of monoterpenoids: 1,8-cineole, α-terpineol, and terpinen-4-ol, generated by hydration of α-terpinyl and terpinen-4-ol cations. During prolonged distillation, the esters may generate the monoterpenes terpinolene, limonene, and α-terpinene. Linalool may form geraniol and/or nerol by allyl rearrangement or may undergo racemization during distillation (Kiran Babu and Singh 2012). A comparison of hydrodistillation and hexane extraction for Australian true lavender flowers indicates higher linalool content (52.59 vs. 33.35%) and lower linalyl acetate level (9.27 vs. 25.73%) for hydrodistilled versus solvent extracted oil (Danh et al. 2013).

In general, lavender essential oils obtained by hydrodistillation are characterized by higher content of alcohols, monoterpene hydrocarbons and shorter shelf-life in comparison with essential oils obtained by solvent or supercritical fluid extraction. The hydrodistilled essential oils have a typical sweet balsamic and herbaceous, floral refreshing odor with woody undertone (Kiran Babu et al. 2016). The formation of various terpineol isomers due to degradation of linalyl acetate during hydrodistillation may modify the scent of true lavender essential oil into geranium or tea-tree oil-like (Wesolowska et al. 2010). Caryophyllene and cadinene derivatives are present in higher concentrations in essential oils isolated by distillation techniques, contributing to the distinctive woody note. These oils are recommended, due to their flavor, for use in colognes, semi-floral and non-floral perfumes and aromatherapy (Kiran Babu et al. 2016). The duration of hydrodistillation should be 2 h to achieve an acceptable quality of lavender essential oil (Kiran Babu et al. 2016). Grinding or ultrasound treatment of French lavandin flowers before hydrodistillation (turbo-hydrodistillation or ultrasound-hidrodistillation) increases herbaceous and camphoraceous nuances of the essential oil scent while salt (salt-assisted extraction-HD) and enzyme pretreatment (enzyme-assisted extraction-HD) confer atypical off-notes (Filly et al. 2016). Compared with steam distillation, turbohydrodistillation of lavandin causes a decrease in linalyl acetate content and an increase in terpinen-4-ol due to linalool degradation. The essential oil obtained by turbohydrodistillation has lower sensory qualities (Périno-Issartier et al. 2013).

Extraction with organic solvents may result in an increased level of coumarins (about 20% higher). The essential oils have a sweet herbaceous, floral, diffusive hay aroma with woody undertone (Kiran Babu et al. 2016).

Microwave-assisted methods enable better extraction of oxygenated compounds compared with conventional methods (Torabbeigi and Azar 2013; Azar et al. 2011). The lavandin essential oil obtained from French plants by microwave steam distillation has a higher content of linalyl acetate and lower values of linalool than the essential oil isolated by steam distillation or hydrodistillation (29.6 vs. 13.7 and 24 vs. 30%, respectively) (Filly et al. 2016).

Coaxial microwave-hydrodistillation produces a lavender essential oil rich in oxygenated monoterpenes (80% for 30 min extraction). Monoterpene hydrocarbons are present in low amounts (below 10%) when using microwave extraction (30 min). Selective extraction of oxygenated monoterpenes by coaxial microwave-hydrodistillation is due to specific microwave interaction and aqueous solubility of some components. Thus, oxygenated compounds such as 1,8-cineole and camphor, which have a high complex permittivity and strong microwave interaction are extracted more easily compared with monoterpenes, limonene and pinene, which have a much weaker interaction (González-Rivera et al. 2016). Microwave hydrodiffusion and gravity (15 min 1,3kWh) gave a lavandin essential oil with excellent quality and natural odor (Périno-Issartier et al. 2013).

Supercritical fluid extraction (SFE) is a fast, selective, and environmentally friendly method. Supercritical CO_2 is the solvent of choice for extraction of plant constituents, as it is non-toxic, non-flammable, thermodynamically stable and enables operation at relatively low pressure and room temperature (Reyes-Jurado et al. 2015; Da Porto et al. 2009). Supercritical fluid extraction of *L. angustifolia* produces oils that contain higher levels of monoterpenesters and oxygenated sesquiterpenes than hydrodistillation, which is advantageous for quality and stability of the aroma (Kiran Babu et al. 2016; Costa et al. 2012). Aroma of super-quality ester rich SFE essential oils, with fresh, herbaceous, sweet floral, fruity and woody warm nuances is preferred in high-grade perfumes, food, and pharmaceutical industries (Kiran Babu et al. 2016). The use of SFE improved the extraction of sesquiterpenes (oxo-cadinol, hexadecanoic acid, and β-selinene) in the volatile fractions of *L. luisieri*, as well as the extraction of oxygenated monoterpenes (*cis* and *trans*-linalool oxide, epoxylinalool, borneol, terpinen-4-ol, and verbenone) from *L. viridis* (Julio et al. 2014; Costa et al. 2012). Terpene hydrocarbons such as α-pinene, camphene, β-pinene, terpinene are not present in essential oils of *L. viridis* isolated by SFE (Costa et al. 2012).

Sub-critical water extraction (SCWE) allows a rapid (55 min) and selective extraction, prevents degradation of volatile and thermosensitive components and has a favorable impact on the environment (Giray et al. 2008). Sub-critical water extraction of Turkish *L. stoechas* led to essential oils with higher level of oxygenated compounds (camphor, myrtenol, verbenone, terpinen-4-ol, α-terpineol) than hydrodistillation (85.59 vs. 84.09%). Also, lower concentrations of hydrocarbons monoterpenes have been detected in essential oils obtained by SCWE than in hydrodistilled oils (0.42 vs. 10.51%). The aroma is more intense and concentrated in SCWE essential oils (Giray et al. 2008). SCWE followed by conventional hydrodistillation of French lavandin flowers produces an essential oil with a typical peppery spicy and citrus bergamot odor, that contains higher levels of linalool than linalyl acetate (27.5 vs. 1.2%) and significant amount of terpinen-4-ol (5.2%) (Filly et al. 2016).

The volatile composition in the scent emitted by lavender flowers has also been characterized by headspace solid-phase micro-extraction (HS-SPME). The method requires smaller sample sizes, minimises the generation of artefacts and it is time-saving. Kim and Lee (2002) reported higher levels of linalyl acetate in essential oils from Korean lavender when using HS-SPME in comparison with solid-phase trapping solvent extraction, simultaneous steam distillation with solvent extraction, and reduced-pressure steam distillation (48.06% compared with 35.44, 2.63 and 4.04%, respectively). Also, high levels of linalyl acetate (43.4–56.7%) were identified in HS-SPME essential oils of lavender buds from different geographical areas (Se 2013).

Conclusions

Review of data from the last 15 years on lavender essential oils chemical composition revealed an extensive research covering the chemistry of 17 different *Lavandula* species. The most investigated species were: *L. angustifolia, L.× intermedia, L. latifolia, L. stoechas, L. luisieri, L. viridis, L. dentata, and L. multifida*. The studies are highly heterogenous in terms of geographical origin (Europe, North Africa, Asia, North and South America, Australia), plant material (flowers, aerial parts, buds, leaves, leaves with stems, stems), nature of vegetal material (fresh/dried), wild and cultivated plants, method of extraction, and analysis of essential oils. They have been performed mainly in relation with lavender bioactivity, development of better cultivars, physiological modulation of essential oil production, and the assessment of agro-climatic and processing factors influence. The chemical composition of lavender essential oils displays an impressive range of diversity of volatile constituents. For the most *of Lavandula species*, oxygenated monoterpenes are the most abundant components (over 92% in *L. angustifolia, L.* × *intermedia, L. stoechas, L. latifolia*). *Lavandula multifida* and *L. pubescens* show a phenolic type profile (over 60% monoterpene phenols). Linalool, 1,8-cineole, and camphor are distributed as major compounds in the most of studied lavender species. *Lavandula stoechas, L. dentata, L. multifida* and *L. pedunculata* exhibit a pronounced chemotypic differentiation while *L. latifolia* is characterized by an ecotypic differentiation. More research is needed in terms of the knowledge on the genotypic and environmental events that produce the lavender chemical biodiversity, the molecular bases of terpene biosynthesis, the enantiomeric profile of *Lavandula* species essential oils, or the standardization of methodology for the analysis and extraction.

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