ABC AHP NCNPR
Botanical Adulterants Prevention Program
BOTANICAL ADULTERANTS PREVENTION
BULLETIN

VERSION 2
Updated: Sept. 2020

Adulteration of English Lavender (*Lavandula angustifolia*) Essential Oil

By Ezra Bejar, PhD

American Botanical Council, Austin, TX 78723, USA

Correspondence: email

Citation (JAMA style): Bejar E. Adulteration of English Lavender (*Lavandula angustifolia*) essential oil. *Botanical Adulterants Prevention Bulletin*. Austin, TX: ABC-AHP-NCNPR Botanical Adulterants Prevention Program; 2020.

Keywords: Adulteration, essential oil, *Lavandula angustifolia*, English lavender, lavender, common lavender, lavender essential oil, flowering tops

English Lavender *Lavandula angustifolia*
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Goal: The main goal of this bulletin is to provide timely information and/or updates on issues of adulteration and mislabeling of essential oil (EO) of English lavender (*Lavandula angustifolia* Mill.) in particular with lavandin (*Lavandula* × *intermedia* Emeric ex Loisel, syn. *Lavandula angustifolia* Mill. × *Lavandula latifolia* Medik.), spike lavender (*Lavandula latifolia* Medik.), linalool and linalyl acetate- rich EOs, terpenes, and synthetic chemicals.

This bulletin may serve as a guide for quality control personnel, the international herbal products, cosmetic, and essential oil industries, and the extended natural products community in general. It is also intended to present a summary of the scientific data and methods on the occurrence of species substitution, adulteration, the market situation, and economic and safety consequences for the consumer and the industry.

1. General Information

1.1 Common name: English lavender*

1.2 Other common names:[1-5]†

English:	lavender, true lavender, common lavender, garden lavender, narrow-leaved lavender
Chinese:	xun yi cao (薰衣草)
Danish:	ægte lavendel, almindelig lavendel, lavendel
Dutch:	echte lavendel, smalbladige lavendel
French:	lavande, lavande des Alpes, lavande à feuilles étroites, lavande fine, lavande vraie, lavande officinale
German:	echter Lavendel, Lavendel
Greek:	levanta, lebanta (λεβάντα)
Hebrew:	lavender (רדנבל)
Italian:	lavanda vera, lavandula vera, lavandula spica, spigo
Norwegian:	lavendel
Polish:	lawendel
Portuguese:	lavanda, lavanda-inglesa, alfazema

* English lavender is the standardized common name for *Lavandula angustifolia* specified in the *American Herbal Products Association's Herbs of Commerce*, 2nd edition, and is used as common name throughout this manuscript. However, in other areas of the world, the term "English lavender" is considered outdated, and the common name "lavender" is most frequently used.

† Some of the vernacular names are used for several lavender species, including *Lavandula angustifolia*.

Russian: Лаванда узколистная (lavanda uzkolistnaya), Лаванда настоя́щая (lavanda nastoyáshchaya)

Spanish: alfazema, alhucema, aljucema, espigol, espigola, espigolina, esplego, espliego, espliego común, espliego de la hoja angosta, espliego francés, espliego morisco, espligo, espígola, lavanda, lavándula hembra, lavándula macho, tuma

Swedish: lavendel

Turkish: lavanta, tibbi lavanta

1.3 Accepted Latin binomial: *Lavandula angustifolia* Mill.

1.4 Synonyms: *Lavandula officinalis* Chaix, *L. vera* DC, *L. spica* Loisel. *L. vulgaris* Lam.[6-11]

1.5 Botanical family: Lamiaceae

1.6 Distribution:

Lavender is a group of aromatic dwarf shrubs originally from the Mediterranean basin. The plants thrive in rocky, calcareous areas of low-altitude mountains located between 500-1600 m.[10,12-14] English lavender grows naturally in Italy, southern France, Spain, and northeastern Africa.[10] It is now extensively cultivated in Bulgaria, China, France, Morocco, Spain, Ukraine, and the United Kingdom. Smaller producing countries include Algeria, Australia, Argentina, the Balkans, Brazil, England, Hungary, India, Italy, Japan, New Zealand, Russia, South Africa, Turkey, and the United States.[10,15,16]

1.7 Botanical description and growing range:

Lavandula angustifolia is an aromatic shrub, generally up to 50-60 cm high, although some cultivars can grow taller.[17-19] The inflorescence stalk is usually unbranched, 10–25 cm long, with a compact spike usually 4–5 cm but up to 8 cm, sometimes with a lower flower cluster distant from the main spike. The spike has 6–10 flowers, with shades of blue/mauve, white, rarely violet pink in color. The peduncle is about three times longer than the spike; pedicel 1.0–1.5 mm long; calyx 4–7 mm long, densely grey stellate, tomentose outside, with 13 longitudinal ribs.[11] Bracts broadly ovate-rhombic to obovate, bracteoles present but minute. The leaves are clustered on leafy shoots, but widely spaced on flowering shoots. The petiole is very short with a linear-lanceolate to linear blade. The leaves are 17 mm long and 2 mm wide, and 2–6 cm long and 3–6 mm wide on leafy and flowering shoots, respectively.[11]

1.8. Raw material forms:

According to the International Organization for Standardization (ISO),[20] and the European Pharmacopoeia (Ph. Eur.),[21] the essential oil of English lavender is defined as the oil obtained by steam distillation of the flowering tops of *L. angustifolia* Mill., wild or cultivated, of the Lamiaceae family. The standards favor varieties (e.g., Fine, Mailette, Munstead, Raya, etc.) that are relatively low in camphor content[22,23] and have a desirable profile for the pharmaceutical as well as the fine perfumery trade, whereas other varieties, including those yielding higher concentrations of camphor are traditionally used by aromatherapists.[24]

The French government established more stringent compositions and organoleptic requirements for meeting the Appellation d'Origine Protégée (AOP) or protected geographic origin.[25] AOP essential oil guarantee requires the use of *L. angustifolia* species from a strictly defined zone in four different French counties — Drôme, Vaucluse, Alpes de Haute Provence, and Hautes Alpes, and from plants growing at an altitude of a minimum of 800 meters.[25] The lavender oil must meet organoleptic standards and each batch is analyzed anonymously (blindly). The French National Institute of Origins and Quality (known as the INAO) issues this certification.

Table 1. Composition of [English] lavender and lavandin oils according to authoritative sources (in % of the essential oil)[20,21,26-28,30]

	English lavender			Lavandin Abrial	Lavandin Grosso	Spike lavender
Compound	**ISO[a]**	**EP**	**WHO**	**ISO**	**ISO**	**ISO**
Limonene	0-1.0	≤ 1.0	< 1.0	0.5-1.5	0.5-1.5	0.5-3.0
1,8-Cineole	0-3.0	≤ 2.5	< 2.5	6.0-11.0	4.0-7.0	16.0-39.0
β-Phellandrene	0-1.0	-	-	-	-	-
cis-β-Ocimene	0-10.0	-	-	[b]	[b]	-
trans-β-Ocimene	0-6.0	-	-	[b]	[b]	-
3-Octanone	0-5.0	0.1-5.0	<2.5	-	-	-
Camphor	0-1.5.0	≤ 1.2	<1.2	7.0-11.0	6.0-8.0	8-16
Linalool	20.0-45.0	20.0-45.0	20-45	26.0-38.0	24.0-35.0	34.0-50.0
Linalyl acetate	25.0-47.0	25.0-47.0	25-46	20.0-29.0	28.0-38.0	≤ 1.6
Lavandulol	0-3.0	≥ 0.1	-	0.4-1.2	0.2-0.8	-
Terpinen-4-ol	0-8.0	0.1-8.0	1.2-6.0	0.3-1.0	1.5-5.0	-
Lavandulyl acetate	0-8.0%	≥ 0.2	>1.0	1.0-2.0	1.5-3.0	-
α-Terpineol	0-2.0	≤ 2.0	<2.0	-	-	0.2-2.0

[a] ISO has separate specifications for essential oils of wild English lavender from France, and of essential oils obtained from plants cultivated by plant cuttings grown in France (Maillette variety), Australia, Bulgaria, Russia, and other countries.[20] The specifications in Table 1 cover the broadest possible range.

[b] Limits for β-ocimene are 1.0-7.0% for lavandin Abrial, and 0.5-1.5 for lavandin Grosso. No distinction between the *cis*- and *trans*-isomers is made.

Note: Natural variation based on provenance, growing, harvest, and post-harvest handling practices will exist.

The requirements for composition and chromatographic profiles of English lavender, spike lavender, and lavandins by gas chromatography (GC) are described by ISO standards.[26-28]

The WHO monograph of Aetheroleum Lavandulae defines lavender oil as the "essential oil obtained by steam distillation from the fresh flowering tops of *Lavandula angustifolia* Mill. or of *L. intermedia* [sic] Loisel (Lamiaceae)." In this regard, WHO differs from other authorities in allowing for the use of lavandin as a source of lavender oil.

The composition of English lavender essential oils and lavandins (Abrial and Grosso varieties) are clearly defined by various authoritative organizations (see Table 1). Nevertheless, some of the essential oils obtained from English lavender contain a substantially different chemical profile and will not meet any of the specifications put forward by standard-setting organizations despite being authentic lavender oils.[29]

1.9 General use(s):

Lavender and lavandin flower essential oil is applied topically for skin conditions, inhaled as a sleep aid, or taken internally to obtain relief from anxiety.[10,31-34]

English lavender has been traditionally employed to treat symptoms of certain nerve-related disorders like minor insomnia.[35] Fresh lavender flowers are added to jams, ice cream, vinegar, and herbal teas. The aromatic oil has a fragrance used to scent many cosmetics, shampoos, and industrial products. Lavender oil is used as a flavor component in food and beverage products (vinegars, baked goods, candy, frozen dairy desserts, gelatins, and puddings).[10] The more expensive English lavender oils are mainly used in the fine fragrance industry. Due to the comparatively high costs of these oils, they are at a particularly elevated risk for economically motivated adulteration.

Several publications suggest external uses of English lavender flower oil for relaxation, the relief of anxiety and depressive mood, and to promote sleep.[10,32-34,36-39]

English lavender oil applied in aromatherapy appears to positively affect individuals' mood, improve sleep patterns, and increase alertness based on assessments of electroencephalographic activity, mathematical computation speed, and sensory evaluation.[36,37,40] While many smaller clinical studies suggest a therapeutic benefit of lavender oil inhalation in patients with anxiety and insomnia, larger studies are needed to generalize these findings.[38,41-43]

In 2016, an oral English lavender oil preparation showed promising results in a randomized clinical trial on individuals with mixed anxiety-depression (MADD). In that study, 318 adult out-patients with MADD were randomized and received either 80 mg English lavender essential oil or placebo once per day in double-blind fashion for a scheduled period of 70 days. Individuals treated with English lavender essential oil had a better overall clinical outcome and showed more pronounced improvements of impaired daily living skills and health-related quality of life.[36]

1.10 Nomenclature considerations: Naming lavender is a challenge for lavender oil producers and traders. Accurate identification of the correct species is difficult due to the existence of hybrids, as well as different varieties depending on where plants grow. Lavender plants can look different morphologically depending on soil conditions and geographic locations.[11,44] Moreover, there are up to 132 scientific plant names of species ranking in the genus *Lavandula*.[44] Of these, only 47 have been accepted as species names.[44]

The common name "lavender" is applied to several species of *Lavandula* generally used for their aromatic quality. In the United States, the Standardized Common Names "English lavender", or "common lavender" are applied to dietary supplements containing *L. angustifolia*. Other *Lavandula* species in the dietary supplement trade include French lavender (*L. dentata*), spike lavender, and lavandin.[6]

The International Nomenclature of Cosmetic Ingredients (INCI) requires the following names to be used on cosmetic products: *Lavandula angustifolia* (lavender) oil, *Lavandula hybrida* (lavandin) oil, and *Lavandula latifolia* (spike lavender) oil for lavender, lavandin, and spike lavender oils, respectively.[45] A confusing factor is the availability of mixtures made with several lavender oils and synthetic linalool and/or linalyl acetate. Common mixtures are lavender 30/32 and lavender 40/42, standardized to 30% linalool/32% linalyl acetate, and 40% linalool/42% linalyl acetate. Some manufacturers use *Lavandula officinalis* (lavender) oil and *Lavandula angustifolia* (lavender) oil, respectively, as INCI names for these ingredients.[45] In such cases, a buyer may believe that the ingredient is a genuine English lavender oil rather than a blend of natural and synthetic ingredients.

2. Market

2.1. Lavender oil production

Lavender cultivars were initiated in the early 1600s in Europe. This coincides with the emergence of writings about the use of essential oils in herbal medicine texts and knowledge of oils becoming more widespread in Europe.[46] By the 1800s, most of the pharmacopeias of England, Germany, and France were referencing and prescribing essential oils for a variety of illnesses. By 2002, worldwide annual lavender essential oil production was estimated at 200 metric tons (MT) with lavender essential oil mainly produced in Europe.[10]

Precise statistics of lavender essential oil production are difficult to obtain. Giray published a report in 2018 which combines information from various sources such as national reports, country studies, and global market

reports of private companies.[44] Estimates in this report suggest world production of lavender essential oil is close to 375 MT. Başer listed production data for essential oils of lavender and lavandin (Abrial, Grosso, Sumian, and Super varieties) in 2019: Lavender production volume was 750 MT, while lavandin volumes were 2100, 100, 50, and 25 MT for Grosso, Abrial, Sumian, and Super, respectively.[47] This contrasts to data from Erich Schmidt, which puts the lavender production closer to 400 MT. (E. Schmidt [Art and Fragrance] email to S. Gafner, March 7, 2020) Europe continues to be the geographic area with the largest production in the global lavender oil market, with almost 80% of the world's total production.[12,44,48]

Bulgaria and France are the largest producers, with Bulgaria alone producing over 200 MT of lavender essential oil in 2017 (Table 2) followed by France with around 100 MT.[44] For over 40 years, China has grown lavender introduced from France.[49] This country has now about 2000 ha. of lavender in production by collectivist units in Xinjiang Autonomous Province. They produce 95 percent of China's lavender-related products.[44,49] Chinese lavender production is quite high at around 40 MT, but the PPRC supplies fewer than 10 MT to the international market.

The essential oil from English lavender plants competes in the marketplace with the essential oil from the hybrid lavandin. Lavandin produces more essential oil on a per plant basis than common lavender.[50] Global lavender usage/consumption compared to lavandin usage/consumption is reflected in its production ratio. The ratio of lavender to lavandin production worldwide was estimated to be about 1:5 in 2012[13] and about 1:3 in 2019.[47]

There is a generalized idea that English lavender grown for the perfume industry is mainly cultivated in Europe, especially France.[13] As described in the previous section, France is still one of the top producers with 109 MT of lavender oil (Table 3).[44]

Lavandin is now extensively cultivated in Spain, France, Italy, the Balkan Peninsula, Australia, and Tasmania.[13] Indeed, France's lavandin production surpassed by far lavender in 2016 with 1,439 MT produced. The second largest producer is Spain with 2000 ha and about 80 MT of lavandin oil produced. Morocco is in third place with 1000 ha of cultivated area for lavandin essential oil production (volume not available).[44]

Changes in production of lavandin versus lavender in France are provided in Table 3. After a drop in the number of farms and cultivated area from 2000-2010, the French lavender/lavandin industry has shown a steady increase in production from 2010-2016.[44]

Spike lavender is another *Lavandula* plant competing with lavender in the marketplace. Spike lavender has its main production areas in Spain but grows wild in a large part of the Mediterranean area, preferring warmer and lower altitude regions than lavender and lavandin.[51] Spain is one of the largest producers of spike lavender essential oil with less than 10 MT a year.[44,51]

2.2. Supply sources of English lavender:

In 2017, the two major European country producers of English lavender oil were Bulgaria with 52%, followed by France with 26%. Bulgaria became the largest producer in 2014 (Table 2).[44,52]

Bulgaria has been revamping its English lavender production significantly year after year. Now, 1,600 farms are producing lavender, four times more than the number of farms that existed in 2017.[44,52] Another major lavender producer is China, with ca. 12% of the total lavender worldwide world production. Other producers include England,

Table 2. Estimates of lavender oil production in Bulgaria from 2011-2017[44]

Year	Oil Production (MT)
2011	45
2013	120
2014	140
2015	200
2016	280
2017	200

Table 3. Lavender/lavandin cultivation areas and essential oil production in France[44]

Year	Number of farms	Production area (ha)	Lavender oil production (MT)	Lavandin oil production (MT)
2000	1739	16274	-	-
2010	1362	15994	35	950
2011	1258	17483	40	1144
2012	1311	19306	53	1087
2013	1324	20274	50	1028
2014	1390	19788	63	1226
2015	1443	20922	82	1374
2016	1496	22213	109	1439

Russia, Yugoslavia, Australia, United States, Canada, South Africa, Tanzania, Italy, and Spain. These countries all together produce about 10% of world production.[13,44]

Australia and New Zealand have recently developed an English lavender oil industry.[53] Lavender is cultivated in South Africa in the Western and Eastern Cape that includes KwaZulu-Natal, Free State, Gauteng, Limpopo, and Mpumalanga provinces.[13]

2.3. Market dynamics:

Market reports provide rather variable numbers on the lavender market. Al-Rajab stated that global market for lavender (including English lavender, lavandin, spike lavender, and others) oil grew from twenty-eight million dollars in 2014 to 36 million dollars in 2017.[54] On the other hand, Persistence Market Research provided a number of US $76 million for the global trade in 2016 alone, and a forecast that the global lavender oil market will reach $124.2 million in 2024.[48]

Lavender production is affected by the weather. Since Bulgaria is the largest producer of English lavender oil, the climatic conditions in the growing areas can have a substantial impact on the availability of English lavender oil, and its pricing. In 2017, late snow in northern Bulgaria, combined with heavy rains and hail in the South led to a poor lavender flower harvest, and an estimated 30% reduction in essential oil production. This sent bulk prices up from US $53 to US $118 per kg within a year.

In a dataset prepared using price data from several recent market reports, the price of English lavender oil ranged from $66-$188/kg in 2018 and lavandin oil ranged from $32-51/kg.[44] The country of origin of the oil and quality appear to be critical to the price, with lavender oil from France being the most expensive at a price of $188/kg. In contrast, Hungarian lavender oil was almost a third of the value ($66/kg) of the French oil.[44] In 2019, prices for bulk lavender oil averaged approximately US $170/kg.[47]

For lavandin oil, several different oil qualities exist (qualities are related to hybrids produced and created in a specific region). One of these hybrids, for example, is Lavandin Grosso, which originated from a crossover between English lavender and spike lavender. The International Organization for Standardization (ISO) has issued standards for English lavender, spike lavender, and two lavandin hybrids: Abrial and Grosso.[20,26-28]

In 2018, French Abrial lavandin oil sold at US $48/kg, and French Sumian at $51/kg. Prices for Grosso were at $32-$34/kg, and Super at $46-$49/kg, depending on the country of origin.[44] In a 2019 presentation, Başer provided a price range US $35-75/kg for lavandin oils, depending on the quality.[47] Prices can vary substantially between local markets and international markets. While lavandin oil prices are reportedly similar, lavender oil prices on the international market can be as much as $40-50/kg higher compared to costs on local French markets.[44]

3. Adulteration

3.1 Known adulterants of lavender essential oil

Adulteration of lavender can be separated into four categories according to Satyal and Sorensen:[55]

1. The sale of essential oil mixtures with a similar composition to lavender, such as lavandin, spike lavender, and essential oils from other *Lavandula* species and hybrids
2. Additions of similar essential oils, or essential oil fractions, to lavender oils
3. The addition of purified or synthetic components to lavender, lavandin, and other essential oils to obtain a product similar to genuine lavender oil in chemistry and odor
4. The undeclared admixture of non-volatile solvents such as glycols, benzyl benzoate, benzyl salicylate, triethyl citrate, or vegetable oils such as coconut oil

Reports of lavender oil adulteration include substitution with lavandin, acetylated lavandin, spike lavender oil, and essential oils from other *Lavandula* species.[18,55-59] Lavandin oils contain many of the chemical constituents present in English lavender oil.[18,60] Spike lavender has altogether a rather different composition compared to English lavender (Table 1); therefore, it can easily be detected and is rarely used as adulterant.[18,28] It is used extensively in low-cost perfumery.[51] Lavandin can be distinguished from lavender oil by the presence of larger amounts of camphor (5-10%), 1,8-cineole (3-8%), and borneol (1.7-3.3%)[18,55] leading to a difference in fragrance reportedly detectable by those trained in sensory assessment.[61]

The lower oil production and higher price of English lavender compared to lavandin oil is the reason why English lavender and lavandin are commonly blended.[60] The pressure to drive economically motivated adulteration is due to relatively high prices of *L. angustifolia* oil.[58,62] Lavender oil can be mixed with spike lavender oil, whose prices are around 1/6 those of English lavender oil.[58,62]

Essential oils and essential oil fractions that are not obtained from *Lavandula* species have also been mentioned in the literature as English lavender adulterants. For example, adulteration of lavender oil with vetiver oil (*Chrysopogon zizanioides* (L.) Roberty, syn. *Vetiveria zizanioides* (L) Nash, Poaceae) has been documented.[56] This plant, originally from India, is used extensively for perfumes, cosmetics, deodorants, lotions, soaps, and aromatherapy applications. Other commercially available essential oils used to adulterate lavender oil include rectified or acetylated Ho wood oil‡ (obtained from *Cinnamomum camphora*, Lauraceae) from China, and eucalyptus (*Eucalyptus globulus*, Myrtaceae), and white camphor oil (from *Cinnamomum camphora*) fractions.[58,63] Ho wood oil serves as a starting material in the manufacture of linalool, linalyl acetate, synthetic lavender oil, and synthetic bergamot oil (synthesized to mimic oil of the fruit peel of *Citrus bergamia,* Rutaceae).[64] Spanish

‡ Ho wood oil, also known as shiu oil, is the essential oil obtained from a specific chemotype of the camphor tree, i.e. a chemotype rich in linalool. Acetylation yields an oil rich in linalyl acetate.

sage (*Salvia officinalis* subsp. *lavandulifolia* (Vahl) Fams, syn. *Salvia lavandulifolia*, Lamiaceae) has been listed as an adulterant of lavender and lavandin oils by several authors.[59,62,63] Another known adulterant is rosewood (*Aniba rosodora*, Lauraceae) oil.[55,58] Additionally, clary sage (*Salvia sclarea*, Lamiaceae) oil, rosemary (*Salvia rosmarinus* Spenn, syn. *Rosmarinus officinalis*, Lamiaceae), and petitgrain (*Citrus aurantium* var. *amara*, Rutaceae) oil, or fractions of these oils, are sometimes used as adulterants.[55,58] Due to the relatively high costs of clary sage, petitgrain, and vetiver oils, these materials are not commonly used to adulterate lavender oil.[55]

Synthetic compounds used to adulterate English lavender essential oil include most often linalool, terpinene-4-ol, and linalyl acetate.[55,56,58,62,65] Limonene, *cis*-ocimene, *trans*-ocimene, 3-octanone, 3-octanol, borneol, and camphor are also used.[55,56,58,62] Another means of adulteration is the addition of a mixture of terpenyl cyclohexanols to increase what perfumers refer to as the sandalwood note (no direct relationship to true oil of sandalwood [*Santalum album* and other *Santalum* spp., Santalaceae]).[65]

There are also reports of lavender oil being adulterated with phthalates.[18,55,58] Diethylphthalate was commonly used as a solubilizer in fragrances, but its use for this purpose is limited nowadays.[66] It may also leach from plastic tubes and other materials due to its frequent use as a plasticizer, and its presence can therefore be accidental in nature.[56]

Misrepresenting the country of origin is an example of mislabeling and, while the product may contain English lavender oil, technically this represents an adulterated product. Beale et al.[67] reported essential oils originating from France and Bulgaria are considered certified essential oils, and therefore are sold and distributed at premium costs compared to lavender oils from Asia. There is anecdotal evidence that such oils may be labeled and sold as English lavender oils from European origin.

3.2. Sources of information supporting confirmation of adulteration:

Lavender essential oil adulteration is well documented and has been reviewed in book chapters or scientific publications,[18,51,56,60,62,68] reported after analysis of commercial lavender essential oils in the peer-reviewed literature,[55,69-73] and on industry web sites.[59,63]

Industrial production of lavender oil started in the mid-eighteenth century[62] and some accidental adulteration may have existed in the past due to the confusion of *Lavandula* species and existence of hybrids.[51] However, lavender varieties, which are not considered English lavender, were also often mixed commercially in the vessels for financial gain.[56,65] In addition, when the plant material has a high proportion of stem and leaf material, the lavender oil is considered less valuable.[74]

One report suggests that lavender and lavandin oils are adulterated while in the stills (apparatus used to distill liquid mixtures), before commencing the distillation of the plant material.[56,62] During a tour of lavender distillation facilities in the French department of Alpes-de-Haute-Provence in 1981, essential oil expert Eric Schmidt sampled a number of production sites for compositional analysis. Evaluation of these materials by GC showed that only one out of 10 samples was authentic, while the other nine samples were adulterated predominantly by adding synthetic linalool and linalyl acetate. Reduced concentrations of lavandulol and lavandulyl acetate were also observed. Some of the materials had relatively high amounts of borneol, camphor, and limonene, suggestive of lavandin oil admixture.[56]

A 2016 investigation into the authenticity of 16 commercial lavender oils reported that half of the samples were adulterated. While samples obtained directly from distillers were all authentic, seven of the nine samples purchased online or from US retail outlets had traces of byproducts from the synthesis of linalool and/or linalyl acetate.[55]

3.3. Accidental or intentional adulteration:

Both intentional and accidental substitution seems to occur, according to anecdotal and scientific evidence. In most cases, intentional adulteration seems to be economically motivated.[56] The scenario is complicated by the large heterogeneity of the *Lavandula* genus and by the number of hybrids that exist in cultivars and in nature.

Some information on the reasons for the adulteration of English lavender can be obtained from accounts of scientists visiting manufacturing facilities. Schmidt, who inspected many essential oil producing facilities in the top country producers of Bulgaria and France, reported evidence of intentional adulteration with synthetic material.[56]

In one case in France, Schmidt found a separate pump spreading synthetic chemicals directly over 100% pure lavender oil before being distilled.[56] In this example, the adulteration is clearly intentional, and has even occurred in some instances where the company claimed lavender oil from direct distillation of organically grown English lavender.

3.4. Frequency of occurrence:

Lavender is considered a high-value essential oil, thus the intentional frequency of adulteration is estimated to be quite high.[63] According to essential oil experts, the frequency of adulteration is close to 90% due to the lower cost of spike lavender and lavandin essential oils.[56,62,69]

As described in section 3.2, random sampling of lavender oil from 10 production facilities found that only one out of the 10 samples had a lavender oil composition meeting the requirements of the ISO standards. The others were adulterated mainly with synthetic linalool and linalyl acetate.[56]

However, few tests have been published and data have been confounded depending on the method and standard used. According to gas chromatography-pyrolysis-isotope mass spectrometry (GC-IR-MS) results, all of the five commercial samples of lavender oil were adulterated by blending with synthetic linalool and linalyl acetate.[70]

In a study where 16 commercial lavender oils purchased from different suppliers in Germany and Switzerland were analyzed, eight were considered adulterated, predominantly with synthetic linalool and/or linalyl acetate. Two of the adulterated oils were of Croatian origin and, since these oils did not meet the specifications of the European Pharmacopoeia, may represent lavender chemovars, or essential oil from a different *Lavandula* species.[57]

Another analysis of 16 commercial lavender oil samples, obtained by lab distillation (1), online purchase (7), directly from distillers (5), or from US distributors (1), or US retail outlets (2), revealed that only seven of them were authentic. Seven of the samples contained markers for synthetic linalool and linalyl acetate.[55]

In a study with four commercial samples of putative lavender oil from Romania, one of the samples was of synthetic origin.[69]

Most of the personal care and home care products such as soaps, body lotions, shampoos, deodorants, or detergents with "lavender" fragrance do not contain English lavender oil. The fragrance is imparted by compounding isolates, such as linalool, linalyl acetate, limonene, and other fragrance components, to make an ingredient that is perceived to smell like lavender by the consumer. Additionally, the use of lavender or lavandin "with other natural flavors" (so-called "WONFs") by formulators is common. These materials contain a small amount of essential oil, which is mixed with "natural" (these are generally made by fermentation) isolates. (S. Gafner, unpublished results)

3.5. Possible safety/therapeutic issues:

Among the essential oils, lavender is one of the most versatile oils, with an extremely diverse range of biological and clinical properties.[10] Lavender oil has been used safely for more than a hundred years, and is generally considered to be safe (GRAS) to be consumed orally and topically for a long time without serious adverse reports in the literature.[7,10,11,31] According to recent reports lavender oil does possess a weak potential for sensitization.[39,75,76]

The safety profile of lavender oil materials has been recently put into question by regulators because of its skin-sensitizing effects. While a list of cosmetic allergens is missing in the United States, European regulators require a warning statement on lavender ingredients. The reason for this requirement is its linalool content since degradation products formed after oxidation (leading to compounds such as linalool hydroperoxides) may cause skin sensitization.[77,78] Companies selling on the European continent must comply with the labeling requirements for their products. Linalool is also required by the International Fragrance Association (IFRA) to have the lowest technically possible peroxide value.[79]

So far, there is no conclusive, significant evidence that skin sensitizations are specifically due to adulterated ingre-

English Lavender *Lavandula angustifolia*
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dients. However, lavandin essential oil has a substantially higher content of camphor compared to lavender oil. Several reports have linked topical camphor application to allergic contact dermatitis,[80-82] but a review on contact dermatitis caused by topically used herbal medicines did not find an elevated risk for lavender, lavandin, and spike lavender oil.[83] Based on its established toxicity,[84] camphor-containing ingredients should not be administered to toddlers and small children.[85]

3.6. Analytical methods to detect adulteration:

Official analytical tests for purity and identity include organoleptic evaluations, physical tests (relative density, refractive index, optical rotation, miscibility in ethanol) and chemical tests (acid value, ester value, and composition by thin-layer chromatography [TLC] and GC).[11,20,21] All lavender oils can be characterized and identified by a specific chemical fingerprint.[20,21] Flowers produced in the Mediterranean climates, especially on higher elevations; yield different essential oils than those growing in colder climates. The composition of the essential oil varies depending on many factors including mode of cultivation and environmental conditions.[7,20]

Oils of lavender and lavandin can be discerned from other essential oils using organoleptic methods. Both oils are pale yellow and have a characteristic aroma.[20,56] ISO standard 3515 shows character and data for lavender oils from various origins.[20]

According to the European Pharmacopoeia, the authenticity assessment of lavender oil is based on the quantification of characteristic compounds, such as linalool, linalyl acetate, limonene, 3-octanone, 1,8-cineole, camphor, terpinen-4-ol, lavandulyl acetate, lavandulol, and α-terpineol by means of capillary GC.[21] The calculation of relationship coefficients can also be used to detect mixtures of lavender oils with natural fractions or isolates. The ratio between *cis*-β-ocimene and *trans*-β-ocimene, *trans*-β-ocimene and 3-octanone, and linalool plus linalyl acetate to lavandulol plus lavandulyl acetate can be determined by GC and then compared to values for authentic lavender oil.[56] Several authors indicate lavandulol and lavandulyl acetate as marker compounds for lavender essential oils.[56,63] Absence of, or low concentrations of lavandulyl acetate (< 3%) and cryptone (< 0.1%), a minor compound in English lavender oil, were used by Satyal and Sorenson as a criterion to detect adulteration based on testing hundreds on commercial lavender oils from around the world.[55] The presence of byproducts from chemical synthesis,§ e.g., dehydrolinalool, dihydrolinalool, dehydrolinalyl acetate, dihydrolinalyl acetate, plinol, and plinyl acetate, are indicators of adulteration with synthetic linalool and linalyl acetate.[55,56,86-88]

The preferred method of analysis for lavender oil is conventional GC according to ISO and Ph. Eur. using a flame ionization detector (FID).[20,21] However, numerous other authors have published GC methods for the detection of adulteration.[67,70,72,73,89-92] Newer methods have used enantioselective-GC methods to measure the abundance of (*R*)-linalool, (*S*)-linalool, (*R*)-linalyl acetate, and (*S*)-linalyl acetate.[57,59,70,73,91,93] The (*R*)-enantiomers of linalool and linalyl acetate dominate in English lavender essential oil, making up generally between 88-97% of linalool, and over 99% of linalyl acetate,[57,73,94-96] while synthetically produced linalool and linalyl acetate are racemic mixtures of the enantiomers.[70] A complicating factor is that linalool in lavender oil may undergo partial racemization when proper processing conditions are not followed. Linalyl acetate which remains unaltered by the extraction process or the acidity of the plant, can be added as a more reliable target for enantiomeric analysis.[73] Besides the use of chiral columns to measure the abundance of linalool and linalyl acetate enantiomers, the determination of $^{2}H/^{1}H$ isotopic ratios alone or in combination with $^{13}C/^{12}C$ and $^{18}O/^{16}O$ ratios using GC-MS has been used to detect adulteration.[70,72] Isotope ratios of linalool and linalyl acetate can be determined, and characteristic ranges of authenticity can be deduced. This method together with enantioselective multidimensional gas chromatography-mass spectrometry (MDGC-MS) allows differentiation between lavender oil and other species of *Lavandula*.[70] The combination of GC-MS with chemometric tools, such as multivariate curve resolution (MCR) has also been reported.[62,67,71]

Beale et al. tested 54 English lavender oils originating from Europe (n = 30) and Asia (n = 24) using a non-targeted predictive model and found that samples from both continents met current standard test methods specifications such as the ISO Standard 11024.[97] They concluded such methods for the identification of lavender oil cannot determine all quality classes of lavender oil. The reason for this is the application of limits to the percentage abundance of only seven (out of 170) identified compounds which is an oversimplification for the distinction among subtle differences in very complex oils from different origins. The authors expanded the analysis to include all 170 identified compounds within the lavender oils and analyzed the correlations between their percentage abundance using multivariate statistics.[67] A chemometric model was developed based on the analysis and it identified 15 unique compounds that differentiated between the European and Asian lavender oils, but also displayed little inter-variation between samples of the same cohort. A rapid distinction of the oils was possible using a Partial Least Squares-Discriminant Analysis (PLS-DA) model without the issues of sample-to-sample variation that is inherent to biological samples.[67]

Several other methods to distinguish between lavender and lavandin oils have been published. Lafhal et al. used mid-infrared (MIR) and Raman spectroscopy with subsequent multivariate statistical analysis to differentiate among essential oils from three lavender (n = 55) and four lavandin (n = 80) cultivars collected in southeastern France. High amounts of camphor (3.17-10.14%) were correlated to lavandin oils, while the comparatively high concentrations in β-caryophyllene (2.65-7.07%) were used as a marker for lavender oils. Overall, MIR performed better in predicting the identity of lavender and lavandin oils than Raman spectroscopy.[98] The results also showed that many of the French essential oils did not comply with ISO or Ph. Eur. standards. Good quantitative data were obtained for linalool and linalyl acetate using MIR and near-infrared (NIR) methods.[99] A high-performance liquid chromatography (HPLC) method with polarimetric detection for the distinction between lavender and lavandin oils was published in 2020.[96] Nuclear magnetic resonance (NMR) has also been used as an alternative for the quality assessment of lavender oil.[100] While these chemometric tools are promising, the key to a successful outcome is in having enough samples to provide a robust assessment, and in having the right algorithm to build a model that can reliably distinguish among the essential oils.

§ Linalool is commercially synthesized using acetylene and acetone as starting material, via production of dehydrolinalool, which is then reduced with a Lindlar catalyst to obtain linalool. A small amount is fully hydrogenated into dihydrolinalool. The plinols are formed as a by-product when linalool is produced by semi-synthesis with α-pinene as starting material.

4. Conclusions

English lavender essential oil adulteration is considered to be widespread, even if information on the extent is somewhat scarce. According to the available scientific reports, lavender oil adulteration ranges between 25% to 90%, depending on the analytical method and criteria for adulteration used. Cosmetic and perfume manufacturers, essential oil brokers, suppliers and experts all enumerate different reasons for adulteration occurring:

1. High production cost
2. Low production output
3. Composition is easy to replicate by:
    a. Addition of oils from other plants
    b. Addition of synthetic compounds

English lavender essential oil has two main components, linalool and linalyl acetate, which average about 67% of the oil. According to most authorities, English lavender essential oil is derived from *L. angustifolia,* although WHO also allows *L.* × *intermedia* to be labeled as lavender oil. There are over 200 plant species producing linalool. One of the highest linalool concentrations is found in Ho wood oil. Lavender-like essential oil is also easy to fabricate. Lavandin and spike lavender oils are considered lower quality lavender oil substitutes, which are blended or tweaked to match English lavender oil. Other oils such as eucalyptus and white camphor are used to dilute and adulterate lavender oil as well.

Lavender essential oil is often used for its calming and anxiolytic effects. Many of the lavender benefits are at least in part due to its linalool and linalyl acetate contents. While adulteration with other essential oils, or essential oil fractions, is not generally considered a safety hazard, the consumer may not obtain the expected benefits from the adulterated materials. Unfortunately, there is little or no systematic analysis to discern the difference in benefits between adulterated lavender oil and a 100% pure natural lavender oil.

Scientific reports, information from ISO, and the European Pharmacopoeia provide detailed information on lavender essential oil composition and specifications. Analytical methods to detect adulteration include GC-FID, GC-MS, TLC, NMR, and infrared spectroscopy. One or a combination of these methods can be utilized as a quality control procedure to authenticate lavender oil and ensure a high-quality ingredient. Despite the body of knowledge, many manufacturing companies opt to purchase lower-cost adulterated oils from suppliers with insufficient quality control measures and low traceability.

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REVISION SUMMARY

Version # , Author,	Date Revised	Section Revised	List of Changes
Version 1, E. Bejar	N/A	N/A	None
Version 2, E. Bejar	Sept. 3, 2020	Section 3.6	Removal of reference: Beaumont C. Origin of synthetic marker in linalool and linalyl acetate. International Symposium of the Science of Botanicals (ICSB); 2019; Oxford, MS.