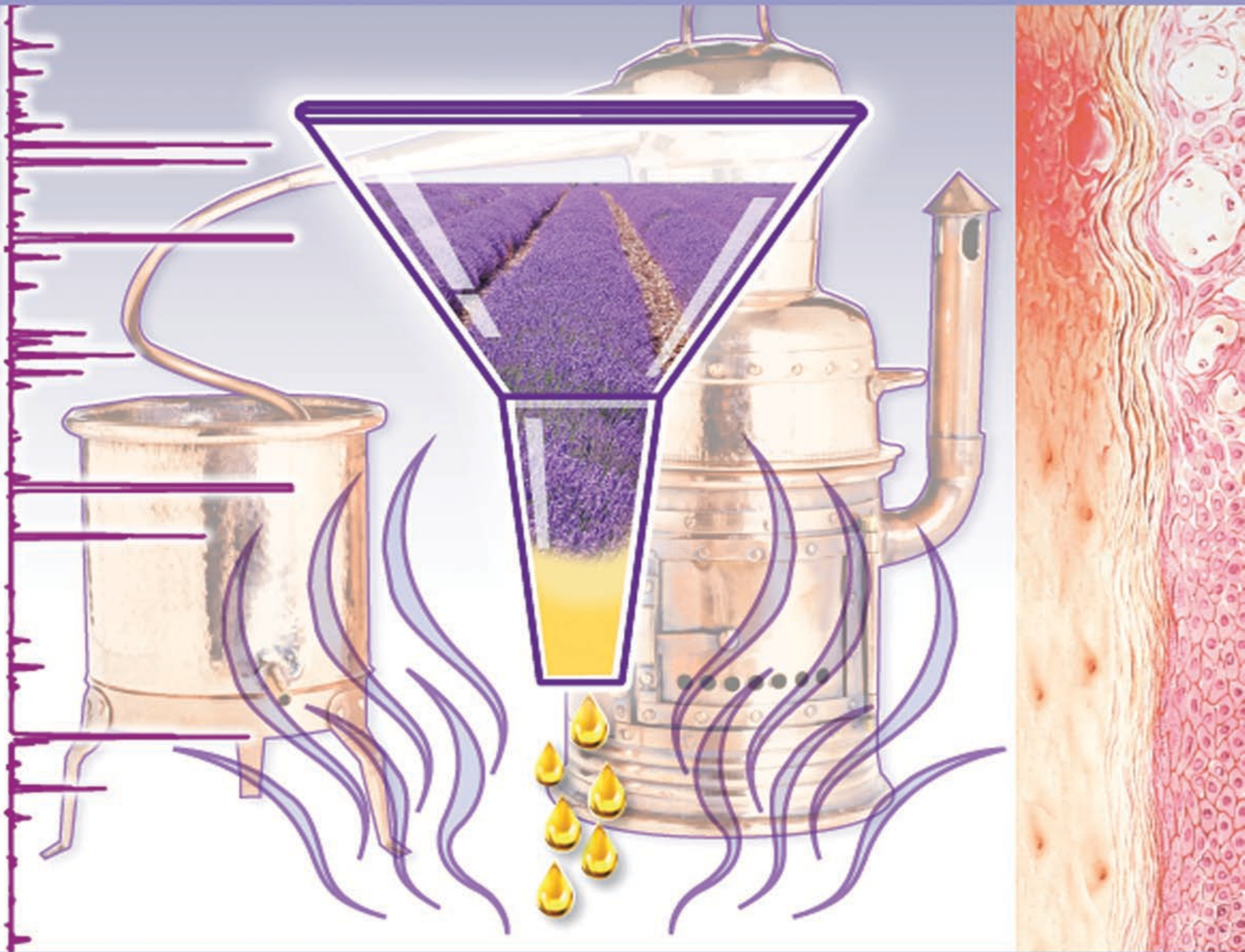
Essential Oils

CONTACT ALLERGY AND CHEMICAL COMPOSITION



Anton C. de Groot • Erich Schmidt

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Preface

Essential oils are complex substances, which are usually obtained by steam-distillation of plant material or – in the case of citrus fruits – by cold-pressing. As a group, they have widespread applications in foods, drinks, perfumes, cosmetics, and other products. Most have long been used for therapeutic purposes; currently, aromatherapy with essential oils enjoys great popularity. Under normal conditions of established use, most oils appear to have a good safety profile, but toxicity may sometimes be observed. Allergic reactions have long been known to occur, e.g., from cassia oil, cinnamon bark oil, and costus root oil. Dermatologists, notably those who are interested in dermato-allergy, have been confronted in increasing frequency with allergic reactions to essential oils in the past 25 years. Possible explanations include Increase in use of essential oils for skin application, availability of commercial preparations for patch testing, more liberal patch testing of essential oils and such test materials in patients with suspected contact dermatitis (‘seek and you shall find’) and current awareness among dermatologists of possible allergic reactions to essential oils.

When contact allergy to one or more essential oils has been detected by patch testing, its relevance is sometimes obvious (aromatherapists with hand dermatitis, patients who have applied tea tree oil for therapeutic purposes), but far more often is difficult to assess: the dermatologist and the patient cannot find a source of contact with the oil. One of the explanations for this may be that the oils or their ingredients can be present in a large array of applications and that they are ‘hidden’ in products where no details on composition are available, e.g., in perfumes or in household products. Another observation is that, in patients with established allergic contact dermatitis from essential oils, virtually never attempts are made to identify the allergenic component(s). Doing this is important, however, as the exact allergens must be known, in order to be able to adequately instruct the allergic patient, which chemicals and products should be avoided to prevent recurrences of allergic contact dermatitis. In some cases, co-reactivity (other positive patch test reactions) to fragrance materials, which are present in high concentrations in the reacting oils, hint at the offending chemical, e.g., in the case of positive reactions to geraniol and rose or geranium oil, to eugenol and clove or bay oil, to citral and citronella oil, or to cinnamaldehyde and cassia or cinnamon oil. However, with the exception of tea tree oil, the allergenic ingredients in essential oils are largely unknown. Besides that, it may be assumed that the composition of essential oils is virtually unknown to most dermatologists, as such information is never published in dermatological journals.

The goal of this book, initiated by the senior author Anton de Groot, dermatologist, primarily was to improve the dermatologists’ level of knowledge and quality of patient care, by fully reviewing the literature on contact allergy to essential oils and their chemical composition. He soon found that for the section of Chemical composition, additional expertise was needed, which was found in the person of the second author, Erich Schmidt.

In our literature search, we have found 79 essential oils which have caused contact allergy or allergic contact dermatitis. For some oils, only one or two such reports are available; for others, however, there is a considerable amount of literature, e.g., tea tree oil, ylang-ylang oil, lavender oil, rose oil, turpentine oil and sandalwood oil.

Next to fully reviewing contact allergy to essential oils, we also present the (possible) chemical composition of these essential oils. Such data are essential to dermatologists for adequately diagnosing and counseling their patients with (suspected) contact allergy to and allergic contact dermatitis from essential oils. Where limited information, e.g., on the main components and their concentrations, would be sufficient for most dermatologists, we decided to present detailed and extensive compositional data to fit the need for information of other professionals, such as chemists working in the perfume industry.

There are 93 chapters (91 oils and 2 jasmine absolutes) on chemical composition, which means that the number of chapters exceeds that of the oils which have caused contact allergy. This is due to the fact that some oils may be obtained from different species (e.g., cedarwood oil Atlas, cedarwood oil China, cedarwood oil Himalaya, cedarwood oil Texas, cedarwood oil Virginia), from different parts of the same plant (e.g., cinnamon bark oil and cinnamon leaf oil; clove bud oil, clove stem oil, and clove leaf oil) or from various cultivars producing different oils (lavandin abrial oil, lavandin grosso oil). In dermatological literature, however, such data are virtually never provided (‘cedarwood oil’, ‘clove oil’, ‘lavandin oil’) and therefore we chose to present the data from all possible source species and plant parts.

We have used two sources of information on the chemical composition of essential oils. The first is literature data of analytical studies. The search for relevant scientific articles has resulted in a very heterogeneous set of data for individual oils. For some, we found only a few analyses; others have been investigated in 60 to over 100 published reports. Only few studies report the results of analyzing a large number of commercial essential oils (notably with citrus oils); in the majority, only one, two or a few samples of oil hydrodistilled in the laboratory with Clevenger-type apparatus have been analyzed. The number or articles reviewed exceeds 2,500.

The second source of information on the composition of essential oils is the very large and unique set of analytical data (nearly 6,400 samples investigated), generated by GC-MS equipment by the second author between 1998 and 2014, while he was working in a German company, which designs and produces natural compositions of fine essential oils and perfume oils. The samples of essential oils came from all over the world. The number of analyses per oil discussed in this book varies from 0 (neem oil, cassia leaf oil) to 422 (sweet orange oil). All analytical results (chemicals identified, range of concentrations) are presented in this book. They have not previously been published and represent by far the largest set of essential oils analyses ever reported in scientific literature.

The extensive and in-depth information provided in this book, most of which cannot be found *as such* anywhere else in literature, should be of interest not only to dermatologists and their patients allergic to essential oils or individual fragrances, but also to academic scientists working in the field of essential oils and fragrances, cosmetic chemists, analytical chemists, perfumers, aromatherapists, other professionals working with (products containing) essential oils, legislators, relevant non-governmental organizations, and to individuals involved in the producing, selling and acquisition of essential oils.

Anton C. de Groot
Erich Schmidt

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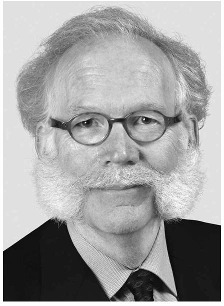
We are grateful to Kurt Kitzing GmbH, Hinterm Alten Schloss 21, 86757 Wallerstein, Germany, for permission to publish the data of the analyses performed by Erich Schmidt during his employment with the company (www.kurtkitzing.de).

The authors thank the American Chemical Society, 1155 Sixteenth Street, NW, Washington, DC 20036, USA, for allowing us to publish the CAS (Chemical Abstract Service) numbers of the chemicals mentioned in this book; CAS Registry Number is a Registered Trademark of the American Chemical Society (www.cas.org; www.acs.org).

We appreciate that the International Organization for Standardization (ISO), Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, has agreed that we publish quantitative ISO norms for essential oils for a reasonable fee (www.iso.org).

ABOUT THE AUTHORS



Anton C. de Groot (1951) received his medical and specialist training at the University of Groningen, The Netherlands. In 1980, he started his career as dermatologist in private practice in 's-Hertogenbosch. At that time, he had already become interested in contact allergy and side effects of drugs by writing the chapter 'Drugs used on the skin' with his mentor prof. Johan Nater, for the famous series 'Meyler's Side Effects of Drugs'. Soon, the subject of the chapter in new Editions and the yearly 'Side Effects of Drugs Annuals' would be expanded to include oral drugs used in dermatology and cosmetics (1980-2000). Contact allergy to cosmetics would become de Groot's main area of interest and expertise and in 1988, he received his PhD degree on his Thesis entitled 'Adverse Reactions to Cosmetics', supervised by prof. Nater. Frustrated by the lack of easily accessible information on the ingredients of cosmetic products, and convinced that compulsory ingredient labelling of cosmetics (which at that time was already implemented in the USA) would benefit both consumers and allergic patients and would lead to only slight and temporary disadvantages to the cosmetics industry, De Groot approached the newly founded European Society of Contact Dermatitis and became Chairman of the Working Party Community Affairs. The European Commission and its committees, elected legislators, national trade, health departments and the cosmetics industries were extensively lobbied. This resulted in new legislation by the Commission of the European Communities in 1991, making ingredient labelling mandatory for all cosmetic products sold or disposed of in EC Member States by December 31, 1997.

Anton has been the chairman of the 'Contact Dermatitis Group' of the Dutch Society for Dermatology and Venereology from 1984 to 1998. In 1990, he was one the founders of the Dutch Journal of Dermatology and Venereology and was Editor of this scientific journal for 20 years, of which he served 10 years as Editor-in-chief. De Groot has authored 12 books, mostly dermatology books for medical students, general practitioners, 'skin therapists' (huidtherapeuten, a paramedical profession largely restricted to The Netherlands) and podotherapists; in addition, he wrote a booklet 'Living with Eczema' for patients with atopic eczema and their parents. His two international books ('Unwanted Effects of Cosmetics and Drugs used in Dermatology' and 'Patch Testing') have both had three editions, the most recent one for Patch Testing in 2008 (www.patchtesting.info). In addition, Anton has written more than 60 book chapters and over 300 articles in Dutch and international journals. He served as board member of several journals and is currently member of the Editorial Advisory Board of the Journal 'Dermatitis'. His most recent project is a new book 'Cosmetic Allergy – Cosmetic Allergens'. He has retired from dermatology practice, but regularly teaches general dermatology to junior medicals doctors at the University of Groningen.

Erich Schmidt (1950) completed his study of business economics at the Landshut University of Applied Sciences, Bavaria, Germany. In 1977 he started his career in a middle sized German company, which designs and produces perfume compositions on conventional or natural base for all kinds of applications and also trades essential oils. Since first working with essential oils, his interest in analyzing their composition increased. After training as perfumer and having become manager responsible for purchase and quality control, he established an analytical laboratory and by autodidactic training, results soon were equal to those found in science. With spreading use of aromatherapy in Germany, he provided this field with information about risks, safety evaluation and genuineness of essential oils. Seminars as well as many lectures in symposiums on the subject of aromatherapy have been helpful to teach aromatherapists and nursing staff of hospitals the proper handling and application of the oils. In 1989 he was appointed member of the German delegation and in 1995 became the German responsible representative of ISO (International Organization for Standardization) Technical Committee 54, Essential oils. Several ISO standards have been established under his responsibility. As manager of the company, he was member of the board of the German organization of the fragrance industry (DVRH; Deutscher Verband der Riechstoff-Hersteller; www.riechstoffverband.de) from 2002 to 2012. His special expertise was the field of natural substances and their composition, which led to a closer cooperation between the DVRH and the IVDK (Informationsverbund Dermatologischer Kliniken; www.ivdk.org). His interest then concentrated on the safety of natural chemical substances, both including essential oils and extracts. A number of articles on essential oils were published in the journals Forum Essenzia and Euro Cosmetics. From 2004, he decided to focus more on scientific work in cooperation with the division of Clinical Pharmacy and Diagnostics of the University of Vienna, Austria, in the fields of clinical pharmacy, biological activity of essential oils and single odorant compounds and analyses of pharmaceutically used lipophilic plant compounds. Since 2005, he authored or co-authored more than 90 publications in journals such as Natural Product Communications, Journal of Essential Oil Research, Journal of Essential Oil Bearing Plants, Perfumer & Flavorist, Bioscience, Biotechnology, and Biochemistry, Ernährung, Österreichische Zeitschrift für Wissenschaft,Technik, Recht und Wirtschaft, The International Journal of Essential Oil Therapeutics, Journal of Agricultural and Food Chemistry, Recent Research Developments in Agronomy & Horticulture, Scientia Pharmaceutica, Planta Medica, Recent Progress in Medicinal Plants and Contact Dermatitis. He also contributed a chapter to the 'Handbook of Essential Oils'.

Chapter 1 INTRODUCTION

1.1 WHY A BOOK ON CONTACT ALLERGY TO AND CHEMICAL COMPOSITION OF ESSENTIAL OILS?

Essential oils are complex substances that are usually obtained by steam-distillation or hydrodistillation of plant material. Citrus oils, originating from the peels of *Citrus* species such as grapefruit, lemon, mandarin, orange, or tangerine, are produced by a process called cold-pressing (Chapter 2). Various plant parts can be used for essential oil production, e.g., fruits (oils of angelica fruit, aniseed, carrot seed), roots (oil of angelica root, lovage, valerian, vetiver), flowering aerial tops (oils of sweet basil, clary sage, lavandin, lavender, sage, thyme), leaves (oils of bay, cassia leaf, cinnamon leaf, citronella, clove leaf, laurel leaf), flowers (oils of cananga, chamomile, neroli, rose, ylang-ylang), peels (citrus oils: grapefruit, lemon, mandarin, orange, tangerine), wood (oils of cedarwood, guaiacwood, rosewood, sandalwood), or exudate or oleoresin (oils of elemi, galbanum, olibanum, turpentine). Sometimes more than one part of the plant is used for obtaining the oil, e.g., for dwarf pine oil (needles, terminal branchlets), rosemary oil (flowering tops and leaves) and petitgrain bigarade oil (leaves, twigs, little green fruits). Some plants can be utilized for producing different essential oils, for example, cinnamon bark and cinnamon leaf oil, angelica fruit and angelica root oil, and oils of clove from bud, stem or leaves of the clove, *Syzygium aromaticum* (L.). Three entirely different oils can be obtained from *Citrus aurantium* L., the bitter orange: neroli oil from the flowers, bitter orange oil from the fruit peels and petitgrain bigarade oil from the leaves, twigs and little green fruit.

Essential oils are produced in many parts and countries of the world and are very important trade commodities. As a group, they have widespread applications in foods, soft drinks, alcoholic beverages, perfumes, cosmetics, toothpastes and dentifrices. Many are added to topical pharmaceutical preparations; some are used in products such as incense or cigarettes. Most have long been used for therapeutic purposes to treat a wide range of diseases and ailments. Some are employed in food preservation, in farm animal health, and in agriculture, where they may be applied as pesticides (4). A rapidly growing application of essential oils is in aromatherapy (1–3). Aromatherapy has been defined as the therapeutic application of essential oils and aromatic plant extracts in a holistic context, to maintain or improve physical, emotional and mental well-being (1) or briefly the therapeutic use of essential oils (2). The oils are usually applied to the skin, but can also be given orally, by inhalation, by distribution through the air or by other means.

Under normal conditions of established use, most oils appear to have a good safety profile. However, toxicity may sometimes occur. The majority of adverse events are mild, but serious toxic reactions from some essential oils have been observed, including abortions or abnormalities in pregnancy, neurotoxicity manifesting as seizures or retardation of infant development, bronchial hyper-reactivity and hepatotoxicity; accidental ingestion by young children has occasionally proved fatal (4). Allergic reactions to essential oils may also occur, e.g., from cassia oil, cinnamon bark oil, and costus root oil, which are considered too hazardous for use in aromatherapy by some authors (3).

The interest of the senior author (Anton de Groot, dermatologist) in allergic contact dermatitis, especially allergic reactions to cosmetic products, is the basis of this book. Dermatologists, notably those who are interested in dermato-allergy, have been confronted in increasing frequency with allergic reactions to essential oils in the past 25 years. This development may be explained by the following.

Increasing use of essential oils on the skin

The use of essential oils applied to the skin, either in undiluted form (rare, usually self-medication) or in products containing considerable quantities of essential oils, appears to be increasing. Oils may be applied by the user himself or through massages performed by professionals such as aromatherapists, masseurs, or physiotherapists.

Although in lower concentrations, essential oils may be present in a wide range of consumer products with which we have regular contact, including perfumes and (other) cosmetics.

Availability of commercial test preparations

In the last two decades, a large number of essential oils have become available as commercial preparations for patch testing (Chapter 3). Patch testing is the diagnostic procedure performed in patients with suspected allergic contact dermatitis, and the availability of essential oil test materials has greatly facilitated the detection of contact allergy to these oils.

Increase in patch testing of essential oils by dermatologists in selected patients or in routine testing

Many dermatologists test a series of essential oil test substances, often combined with single fragrance chemicals, in a ‘fragrance series’. This series is usually patch tested in the case of suspected contact allergy to fragrances or in patients who previously had positive patch tests to other fragrances or fragrance markers such as the fragrance mix (I, II or both) or *Myroxylon pereirae* resin (balsam of Peru). Moreover, in the USA, five essential oils (tea tree oil 5%, lavender oil 2%, peppermint oil 2%, jasmine absolute 2% and ylang-ylang oil 2%) are currently present in the screening series of the North American Contact Dermatitis Group (NACDG), which means that they are routinely tested in all patients suspected of contact dermatitis (5). This inevitably results in more cases of contact allergy to essential oils being detected.

Current awareness of possible allergic reactions to essential oils

Many articles on contact allergy to essential oils have recently been published in various dermatological journals, and cases have been presented during congresses.

Two societies of dermatologists and other professionals interested in contact dermatitis (European Society of Contact Dermatitis, American Contact Dermatitis Society) are very active and have their own scientific journals, *Contact Dermatitis* and *Dermatitis*. The large number of publications on tea tree oil allergy certainly boosted awareness and interest in essential oils allergy.

While preparing a manuscript 'Cosmetic allergy – Cosmetic allergens', the senior author made an observation on relevance data in studies on essential oil allergy. The finding of a positive patch test reaction to an essential oil should—as with any test substance—always be followed by determination of its relevance: can the dermatitis of the patient be (partly) explained by contact with the oil or products containing it? In many studies providing results of patch testing with essential oils, no relevance data were provided. In the screening studies of the NACDG, where relevance can be assessed as definite, probable or possible, relevance scores for definite + probable are often <40%, with 'definite relevance' usually being lower than 15% and sometimes even zero. This does not mean, of course, that the patients do not have contact allergy to the oil (or at least the essential oil test substance), but that the dermatologist and the patient cannot find a source of contact with the oil. One of the explanations for this may be that the oils or their ingredients can be present in a large array of applications and that they are hidden in products where no details on composition are available, e.g., in perfumes or in household products. On the other hand, in some cases, contact with the incriminated oil(s) may be easily established, for example, in aromatherapists with hand dermatitis, in patients with dermatitis at the site of therapeutic application of tea tree oil or other oils or in patients developing skin reactions at the site of application of topical pharmaceutical preparations containing essential oils.

Another observation was that, in patients with established allergic contact dermatitis from essential oils, virtually never were attempts made to identify the allergenic component(s). This is important, however, as the exact allergens must be known in order to be able to adequately instruct the allergic about patient which chemicals and products should be avoided to prevent recurrences of allergic contact dermatitis. In some cases, co-reactivity (other positive patch test reactions) to fragrance materials, which are present in high concentrations in the reacting oils, could hint at the offending chemical, e.g., in the case of positive reactions to geraniol and rose or geranium oil, to eugenol and clove or bay oil, to citral and citronella oil, to cinnamaldehyde and cassia or cinnamon oil, to menthol and peppermint oil or to carvone and spearmint oil. Only a few investigators have done analyses of oils that caused allergic contact dermatitis (6-10). In fact, with the exception of tea tree oil which has been extensively investigated by Dr. Björn M. Hausen and his co-workers (11-13) and other German and Austrian investigators (14), the allergens in essential oils are largely unknown. Moreover, we think that the composition of essential oils is virtually unknown to most dermatologists, as such information is not published in dermatological journals, but in journals such as the *Journal of Essential Oil Research*, *Journal of Essential Oil Bearing Plants*, *Journal of Agriculture and Food Chemistry*, *Flavour and Fragrance Journal*, *Industrial Crops and Products*, *Natural Products Research* and many others, which never come to the attention of the dermatological community. Also, no major review articles on contact allergy to essential oils have been published in scientific journals.

Aiming at improving the level of knowledge and quality of patient care, the senior author (Anton de Groot) then considered fully reviewing the literature on contact allergy to essential oils and their chemical composition. An example oil chapter was written and sent to approximately 70 dermatologists all over the world with expertise in contact dermatitis, to verify whether this was considered useful and to ask them for focus points. Virtually all responded positively and enthusiastically and the decision to write the book was made. It was soon realized that for the section on chemical composition, additional other expertise was needed and was found in the person of the second author. Erich Schmidt has worked for decades as a perfumer, analyst, and essential oils specialist in a German fragrance company, has long been a member of an ISO technical committee, and has cooperated with German dermatologists studying contact allergy to essential oils (15).

1.2 CONTACT ALLERGY TO ESSENTIAL OILS: A SURVEY OF OILS AND PLANTS

In our literature search (for specifics see Chapter 5.0 Introduction), we have found 79 essential oils which have caused contact allergy (positive patch test reactions) or allergic contact dermatitis. For some oils, only one or two such reports are available. For others, however, there is a considerable amount of literature on contact allergy and allergic contact dermatitis, e.g., in the case of tea tree oil, ylang-ylang oil, lavender oil, peppermint oil, jasmine absolute, geranium oil, rose oil, turpentine oil and sandalwood oil. Due to the selection criterion (contact allergy reported), the group of 79 oils is very heterogeneous. Some are high volume essential oils, such as orange oil (worldwide production 60,000 tons per year), corn mint oil (35,000 tons) and lemon oil (nearly 9,000 tons); others are produced and commercialized in very small quantities. The estimated commercial quantity of zdravetz oil, for example, which is produced in Bulgaria only, is about 20 kilograms. Costus root oil is apparently still used in aromatherapy (2), but has been forbidden in fragrances and cosmetics in the EU for decades because of its sensitizing properties. Some oils are prohibited by IFRA (International Fragrance Association), including costus root oil, verbena oil, boldo oil, massoia bark oil, rue oil and santolina oil. Others are prohibited or restricted by governmental regulations and laws, as in the case of sassafras oil, rosewood oil, guaiacwood oil and East Indian sandalwood oil. In the case of the latter three, production and export are prohibited as they are endangered species (16).

Table 1.1 provides a list of 91 essential oils and two absolutes (jasmine absolute, which was included because

Table 1.1 List of essential oils

Chapter	Common name	Botanical source	Part(s) of plant used	ISO[a]
5.1	Angelica fruit oil	*Angelica archangelica* L.	Fruit	
5.2	Angelica root oil	*Angelica archangelica* L.	Rhizome and root	
5.3	Aniseed oil	*Pimpinella anisum* L.	Fruit	3475
5.4	Basil oil, sweet	*Ocimum basilicum* L.	Flowering aerial top	11043
5.5	Bay oil	*Pimenta racemosa* (Mill.) J.W. Moore	Leaf	3045
5.6	Bergamot oil	*Citrus bergamia* (Risso et Poit.)	Pericarp (peel)	3520
5.7	Black cumin oil	*Nigella sativa* L.	Seed	
5.8	Black pepper oil	*Piper nigrum* L.	Fruit	3061
5.9	Cajeput oil	*Melaleuca cajuputi* Powell	Leaf, terminal branchlet	
5.10	Calamus oil	*Acorus calamus* L.	Rhizome	
5.11	Cananga oil	*Cananga odorata* (Lam.) Hook f. et Thomson, forma *macrophylla*	Flower	3523
5.12	Carrot seed oil	*Daucus carota* L.	Fruit	
5.13	Cassia bark oil	*Cinnamomum cassia* (Nees & T. Nees) J. Presl	Bark	3216
5.14	Cassia leaf oil	*Cinnamomum cassia* (Nees & T. Nees) J. Presl	Leaf	
5.15	Cedarwood oil, Atlas	*Cedrus atlantica* (Endl.) G. Manetti ex Carrière	Wood	
5.16	Cedarwood oil, China	*Cupressus funebris* (Endl.)	Wood	9843
5.17	Cedarwood oil, Texas	*Juniperus ashei* J. Buchholz	Wood	4725
5.18	Cedarwood oil, Virginia	*Juniperus virginiana* L.	Wood	4724
5.19	Chamomile oil, German	*Chamomilla recutita* (L.) Rauschert	Flowering tops	19332
5.20	Chamomile oil, Roman	*Chamaemelum nobile* (L.)	Flowering tops	
5.21	Cinnamon bark oil, Sri Lanka	*Cinnamomum zeylanicum* Blume	Twig and bark of stem	
5.22	Cinnamon leaf oil, Sri Lanka	*Cinnamomum zeylanicum* Blume	Leaf	3524
5.23	Citronella oil, Java	*Cymbopogon winterianus* Jowitt.	Aerial part (leaves)	3848
5.24	Citronella oil, Sri Lanka	*Cymbopogon nardus* (L.) Rendle	Aerial part (leaves)	3849
5.25	Clary sage oil	*Salvia sclarea* L.	Flowering top (and leaf)	
5.26	Clove bud oil	*Syzygium aromaticum* (L.) Merr. & L.M. Perry	Bud	3142
5.27	Clove leaf oil	*Syzygium aromaticum* (L.) Merr. & L.M. Perry	Leaf	3141
5.28	Clove stem oil	*Syzygium aromaticum* (L.) Merr. & L.M. Perry	Stem	3143
5.29	Coriander fruit oil	*Coriandrum sativum* L.	Fruit	3516
5.30	Costus root oil	*Saussurea costus* (Falc.) Lipsch.	Root	
5.31	Cypress oil	*Cupressus sempervirens* L.	Twig with leaves	
5.32	Dwarf pine oil	*Pinus mugo* Turra	Leaf (needle), terminal branchlets	21093
5.33	Elemi oil	*Canarium luzonicum* (Blume) A. Gray	Wood exudate	10624
5.34	Eucalyptus citriodora oil	*Eucalyptus citriodora* Hook.	Leaf, terminal branch	3044
5.35	Eucalyptus globulus oil	*Eucalyptus globulus* Labill.	Leaf, terminal branch	770
5.36	Galbanum resin oil	*Ferula gummosa* Boiss.	Root exudate	40716
5.37	Geranium oil	*Pelargonium* x spp.	Herbaceous part	4731
5.38	Ginger oil	*Zingiber officinale* Roscoe.	Rhizome	16928
5.39	Grapefruit oil	*Citrus paradisi* Macfad.	Pericarp (peel)	3053
5.40	Guaiacwood oil	*Bulnesia sarmientoi* Lorentz ex Griseb.	Wood	
5.41	Hyssop oil	*Hyssopus officinalis* L. ssp. *officinalis*	Flowering top and leaf	9841
5.42	Jasminum grandiflorum absolute	*Jasminum grandiflorum* L.	Flower	
5.43	Jasminum sambac absolute	*Jasminum sambac* (L.) Aiton.	Flower	
5.44	Juniper berry oil	*Juniperus communis* L.	Fruit, terminal branchlets	8897
5.45	Laurel leaf oil	*Laurus nobilis* L.	Leaf	
5.46	Lavandin abrial oil	*Lavandula angustifolia* Mill. x *Lavandula latifolia* Medik. 'Abrial'	Flowering top	3054
5.47	Lavandin grosso oil	*Lavandula angustifolia* Mill. x *Lavandula latifolia* Medik. 'Grosso'	Flowering top	8902
5.48	Lavandin oil	*Lavandula angustifolia* Mill. x *Lavandula latifolia* Medik.	Flowering top	
5.49	Lavender oil	*Lavandula angustifolia* Mill.	Flowering top	3515
5.50	Lemon oil	*Citrus limon* (L.) Burm. f.	Pericarp (peel)	855
5.51	Lemongrass oil, East Indian	*Cymbopogon flexuosus* (Nees ex Steudel) J.F. Watson	Aerial part (leaves)	4718
5.52	Lemongrass oil, West Indian	*Cymbopogon citratus* (DC) Stapf.	Whole aerial part (leaves)	3217

Table 1.1 List of essential oils (*continued*)

Chapter	Common name	Botanical source	Part(s) of plant used	ISO[a]
5.53	Litsea cubeba oil	*Litsea cubeba* (Lour) Pers.	Fruit	3214
5.54	Lovage oil	*Levisticum officinale* W.D.J. Koch	Root	11019
5.55	Mandarin oil	*Citrus reticulata* Blanco	Pericarp (peel)	3528
5.56	Marjoram oil (sweet)	*Origanum majorana* L.	Flowering top	
5.57	Melissa oil (lemon balm oil)	*Melissa officinalis* L.	Aerial parts	
5.58	Myrrh oil	*Commiphora myrrha* (Nees) Engl. and related *Commiphora* species	Wood exudate	
5.59	Neem oil	*Azadirachta indica* A. Juss.	Seed	
5.60	Neroli oil	*Citrus aurantium* L.	Flower	3517
5.61	Niaouli oil	*Melaleuca quinquenervia* (Cav.) S.T. Blake	Leaves, terminal branchlets	
5.62	Nutmeg oil	*Myristica fragrans* Houtt.	Seed	3215
5.63	Olibanum (frankincense) oil	*Boswellia sacra* Flueck.	Wood exudate	
5.64	Orange oil, bitter	*Citrus aurantium* L.	Pericarp (peel)	9844
5.65	Orange oil, sweet	*Citrus sinensis* (L.) Osbeck	Pericarp (peel)	3140
5.66	Palmarosa oil	*Cymbopogon martini* (Roxb.) Will. Watson	Aerial part (leaves)	4727
5.67	Patchouli oil	*Pogostemon cablin* (Blanco) Benth.	Leaf	3757
5.68	Peppermint oil	*Mentha* x *piperita* L.	Aerial parts, leaf	856
5.69	Petitgrain bigarade oil	*Citrus aurantium* L.	Leaf, twig, little green fruit	8901
5.70	Pine needle oil (Scots pine oil)	*Pinus sylvestris* L.	Needle, twig	
5.71	Ravensara oil	*Ravensara aromatica* Sonn.	Twig with leaves	
5.72	Rosemary oil	*Rosmarinus officinalis* L.	Flowering top, leaf	1342
5.73	Rose oil	*Rosa* x *damascena* Mill.	Flower	9842
5.74	Rosewood oil	*Aniba rosaeodora* Ducke, *Aniba parviflora* (Meisn.) Mez.	Wood	3761
5.75	Sage oil, Dalmatian	*Salvia officinalis* L.	Flowering top	9909
5.76	Sage oil, Spanish	*Salvia lavandulifolia* Vahl	Flowering top	3526
5.77	Sandalwood oil	*Santalum album* L.	Wood	3518
5.78	Silver fir oil	*Abies alba* Mill.	Needles	
5.79	Spearmint oil	*Mentha spicata* L.	Flowering aerial part, leaf	3033
5.80	Spike lavender oil	*Lavandula latifolia* Medik.	Flowering top	4719
5.81	Star anise oil	*Illicium verum* Hook. f.	Fruit	11016
5.82	Tangerine oil	*Citrus tangerina* Hort. ex Tan.	Peel	
5.83	Tea tree oil	*Melaleuca alternifolia* (Maiden et Betche) Cheel; *Melaleuca linariifolia* Smith; *Melaleuca dissitiflora* F. Muell.	Leaf, terminal branchlet	4730
5.84	Thuja oil	*Thuja occidentalis* L.	Twig with leaves	
5.85	Thyme oil	*Thymus vulgaris* L.	Flowering top	
5.86	Thyme oil, Spanish	*Thymus zygis* L.	Flowering top	14715
5.87	Turpentine oil, Iberian type	*Pinus pinaster* Aiton	Oleoresin	11020
	Turpentine oil, Chinese type	*Pinus massoniana* Lamb.	Oleoresin	21389
5.88	Valerian oil	*Valeriana officinalis* L.	Rhizome, root	
5.89	Vetiver oil	*Chrysopogon zizanioides* (L.) Roberty	Root	4716
5.90	Ylang-ylang oil	*Cananga odorata* (Lam.) Hook f. et Thomson, *forma genuina*	Flower	3063
5.91	Zdravetz oil	*Geranium macrorrhizum* L.	Aerial part	
5.92	Cardamom oil	*Elettaria cardamomum* (*L.*) Maton	Fruit	4733
5.93	Cedarwood oil Himalaya	*Cedrus deodara* (Roxb. ex D.Don) G.Don	Wood	

[a] number of ISO standard; International Organization for Standardization, Geneva, Switzerland, www.iso.org

there is quite extensive literature on contact allergy to it) with their common name, botanical source, part of the plant used for obtaining the oil and – if available – numbers of ISO standards (International Organization for Standardization, Geneva, Switzerland, www.iso.org). The number in the left column corresponds to their number in Chapter 5, where all oils are discussed, both contact allergy and chemical composition. The number of chapters exceeds the number of essential oils for which contact allergy has been described. This is due to the fact that some oils may be obtained from different species (e.g., cedarwood oil Atlas, cedarwood oil China, cedarwood oil Himalaya, cedarwood oil Texas, cedarwood oil Virginia; the same goes for lemongrass oil, thyme oil, sage oil), from different parts of the same plant (e.g., cinnamon bark oil and cinnamon leaf oil; clove bud oil, clove stem oil, and clove leaf oil) or from various cultivars producing different oils (lavandin abrial oil, lavandin grosso oil). In dermatological literature, however, such data are virtually never provided ('cedarwood oil', 'clove oil', 'lavandin oil', 'thyme oil') and therefore we chose to present the data from all possible source species and plant parts. Full literature data on contact allergy to / allergic contact dermatitis from individual essential oils are presented in Chapters 5.1-5.93. General aspects (e.g., frequency of contact allergy, relevance of observed positive patch test reactions, clinical picture of allergic contact dermatitis, products responsible for allergic reactions, co-reactivity to other oils and products, the allergens in essential oils, and diagnostic procedures) are discussed in Chapter 3.

1.3 CHEMICAL COMPOSITION OF ESSENTIAL OILS: DATA PROVIDED

The primary goal of this part of the book originally was to aid dermatologists in adequately diagnosing and counseling their patients with (suspected) contact allergy to and allergic contact dermatitis from essential oils. To achieve this, knowledge of the (possible) composition of essential oils used by allergic patients is needed. In the diagnostic phase, compositional information enables or facilitates the identification of the causative allergenic ingredients. In the second phase, counseling allergic patients how to proceed, information on the constituents of essential oils is equally important, as contact with these chemicals has to be avoided to prevent recurrences of allergic contact dermatitis. The advice often given to patients reacting to one or more oils, to simply avoid contact with all essential oils, fragrances and fragranced products, is less than optimal patient care. Every patient who, for whatever reason, wants to continue having contact with (certain) essential oils, needs to be informed which oils are safe to use and which should be avoided. This is certainly critical for patients who work professionally with essential oils, such as masseurs, physiotherapists and aromatherapists, so they can select safe oils and can continue their work activities. Therefore, this book provides not only extensive literature data on reported analyses of essential oils (Chapters 5.1-5.93), but also an alphabetical list of all chemicals identified in this group of essential oils (approximately 4,350) specifying in which they may be present (Chapter 6). Thus, patients who have allergies to specific components (e.g., limonene, linalool, geraniol, citral et cetera) can easily find in which oils these chemicals are present and in which concentrations. Oils not containing the allergens should be safe, unless cross-reactivity can occur, which should be considered by the dermatologist. However, not all oils (possibly) containing the allergen should necessarily be avoided, depending on the concentration range; such data are available in this book.

We have used two sources of information on the chemical composition of essential oils. The first is literature data of analytical studies of essential oils. The search for relevant scientific articles has resulted in a very heterogeneous set of data for individual oils. For some oils, we found only a few analyses; others have been investigated in 60 to over 100 published reports. Only a few studies report the results of analyzing a large number of commercial essential oils (notably with citrus oils); in the majority, only one, two or a few samples of oil hydrodistilled in the laboratory with Clevenger-type apparatus have been analyzed. Some were prepared from plants that were cultivated, but for others, plants growing in the wild or material (plants, fruits, roots) purchased 'at a local market' were used as biomass for oil production. Data collection, selection and interpretation are specified in Chapter 5.0 Introduction. The results of all articles reviewed (over 2,500) are shown in Tables 5.1-5.93.

The second source of information on the composition of essential oils is the very large and unique set of analytical data, generated by GC-MS equipment by the second author between 1998 and 2014, while he was working in a German company which designs and produces natural compositions of fine essential oils and perfume oils.

Although his analytical data reach back to the 1980s, it was decided to include only data from 1998 and later, as the quality of analytical equipment, mass spectra databases (including his own database of >2,500 chemicals) and identification software (17-19) at that time had reached a level which could ensure correct analyses of the oil samples under investigation. With every new database or database version, older data were corrected, if necessary. The results of nearly 6,400 analyses of essential oils and jasmine absolute samples are presented in this book. Oils containing synthetic compounds, indicating clear and intentional adulteration (in which case they are no longer essential oils but perfume mixtures), were excluded. Oils in which chemicals were identified in abnormal concentrations as compared to standards or our own experience were included. Such deviant concentrations can have various causes, including the use of the wrong botanical species, the mixing of biomasses, and intentional adulteration by adding other natural components. Some oils commercialized under the same name can be produced from different species, e.g., eucalyptus oil from *Eucalyptus globulus* and from *Cinnamomum longipaniculatum*, and tea tree oil from various *Melaleuca* species. These were all included in the dataset.

The samples of essential oils (and jasmine absolutes) that have been analyzed came from all over the world and were sent by producers, their agents, wholesalers or other persons or organizations. In most cases, analyses were used to decide whether or not the oil will be purchased. Sometimes analyses were made of 8-10 samples of a particular essential oil from various origins for purchase decisions. Samples were also sent by companies using oils, when they either possess no analytical equipment or do not have enough experience in essential oils analysis. Numerous analyses were commissioned by the German authorities for aiding foreign countries in opening the German market for their agricultural products. Samples were also sent by supervising authorities and organizations to confirm their naturalness and exclude adulterations. Finally, data were generated in so-called round robin tests. In this procedure, various independent laboratories receive an identical group of oil samples, which are analyzed with standardized test methods. The results are then collected and combined to establish the quantity profile for each component of the oil. This is the procedure performed by ISO (International Organization for Standardization; www.iso.org), as well as by other organizations dealing with essential oils, including the European Federation of Essential Oils (EFEO, http://efeo-org.org/) and the International Fragrance Association (IFRA, www.ifraorg.org). Most samples investigated were conventionally produced market oils, but a considerable number were obtained from plants bred in bio culture.

All essential oil samples have been analyzed by the same methods and routine. Gas chromatography–mass spectrometry (GC-MS) was the analytical technique employed using highly sophisticated mass spectra libraries (17-19) and automatic evaluation. This allowed achieving adequate analytical results quantified down to 0.01% on the basis of mass spectra, retention indices and retention times. If necessary, chemicals of special interest (for whatever reason) could be detected down to 1 ppm, although working near the baseline does increase the risk of wrong identifications. All concentrations above 0.09% were given one decimal.

The number of analyses per oil discussed in this book varies from 0 (neem oil, cassia leaf oil) to 422 (sweet orange oil); numbers for each oil are shown in Table 5.0.2 (Chapter 5.0 Introduction). All analytical results (chemicals identified, range of concentrations) can be found in columns A of the main tables of Chapters 5.1-5.93. These results have not previously been published and represent by far the most extensive set of essential oils analyses ever reported in scientific literature.

The extensive and in-depth information provided in this book, most of which cannot be found *as such* anywhere else in literature, should be of interest to dermatologists, academic scientists working in the field of essential oils and fragrances, cosmetic chemists, analytical chemists, perfumers, aromatherapists, other professionals working with (products containing) essential oils, legislators, relevant non-governmental organizations, and patients who are contact allergic to fragrances or essential oils.

LITERATURE

1 Rhind JP. Essential oils. A handbook for aromatherapy practice, 2nd Edition. London: Singing Dragon, 2012

2 Lawless J. The encyclopedia of essential oils, 2nd Edition. London: Harper Thorsons, 2014

3 Davis P. Aromatherapy. An A-Z, 3rd Edition. London: Vermilion, 2005

4 Tisserand R, Young R. Essential oil safety, 2nd Edition. London: Churchill Livingstone Elsevier, 2014

5 Cheng J, Zug KA. Fragrance allergic contact dermatitis. Dermatitis 2014;25:232-245

6 Dharmagunawardena B, Takwale A, Sanders KJ, Cannan S, Roger A, Ilchyshyn A. Gas chromatography: an investigative tool in multiple allergies to essential oils. Contact Dermatitis 2002;47:288-292

7 Zacher KD, Ippen H. Kontaktekzem durch Bergamottöl. Derm Beruf Umwelt 1984;32:95-97

8 Hayakawa R, Matsunaga K, Arima Y. Depigmented contact dermatitis due to incense. Contact Dermatitis 1987;16:272-274

9 De Groot AC, Weijland JW. Systemic contact dermatitis from tea tree oil. Contact Dermatitis 1992;27:279-280

10 Vilaplana J, Romaguera C, Grimalt F. Contact dermatitis from geraniol in Bulgarian rose oil. Contact Dermatitis 1991;24:301

11 Knight TE, Hausen BM. Melaleuca oil (tea-tree oil) dermatitis. J Am Acad Dermatol 1994;30:423-427

12 Hausen BM, Reichling J, Harkenthal M. Degradation products of monoterpenes are the sensitizing agents in tea tree oil. Am J Cont Derm 1999;10:68-77

13 Hausen BM. Evaluation of the main contact allergens in oxidized tea tree oil. Dermatitis 2004;15:213-214

14 Pirker C, Hausen BM, Uter W, Hillen U, Brasch J, Bayerl C, et al. Sensitization to tea tree oil in Germany and Austria. A multicenter study of the German Contact Dermatitis group. J Dtsch Dermatol Ges 2003;1:629-634

15 Uter W, Schmidt E, Geier J, Lessmann H, Schnuch A, Frosch P. Contact allergy to essential oils: current patch test results (2000–2008) from the Information Network of Departments of Dermatology (IVDK). Contact Dermatitis 2010;63:277-283

16 CITES, Convention on International Trade in Endangered Species of Wild Fauna and Flora. www.cites.org

17 NIST/EPA/NIH Mass Spectral Library 2008. Wiley (www.wiley.com), former editions and later upgrades

18 Adams RP. Identification of essential oil components by Gas Chromatography/Mass Spectrometry. Carol Stream, IL, USA: Allured Publishing Corporation, 2001 and later editions

19 Massfinder 4. Hamburg, Germany: Dr. Hochmuth Scientific Consulting, 2014 and previous versions; http://massfinder.com/wiki/MassFinder_4

Chapter 2 ESSENTIAL OILS: GENERAL ASPECTS

2.1 INTRODUCTION

In everyday life man has frequent contact with essential oils or products containing their source materials. It starts in the morning with toothpaste, deodorant, perfume or aftershave, and cosmetics. At breakfast we peel oranges, drink fruit juice, and eat marmalade, and at dinner there are vegetables, spices and foods flavored with essential oils. Environmental contact with essential oil source materials occurs when handling flowers, plants, conifers, wood, cut grass and hay.

It is estimated that essential oils can be obtained from around 30,000 plant species; about 600 of these are or have been used in the past. Currently, the number of essential oils produced is limited to approximately 150, of which 70-80 are high-volume products. In 2009, the world production of essential oils was over 120,000 metric tons (1). Essential oils have many applications in foods, beverages, perfumes and cosmetics. They are also widely employed as pharmacological agents in various forms of medicine, e.g., traditional medicine, folk medicine, Ayurveda and more recently aromatherapy. The largest quantity of essential oils is probably used for flavoring purposes, followed by their use in the fragrance and cosmetics industries.

Many books on essential oils have been published, some focusing on chemistry, others on their use in aromatherapy (e.g., 25-27) or the oils' safety (30); however, the chemical composition of essential oils has – with the exception of *Citrus* essential oils (24) – not recently been presented in extenso. In this book, all possible chemical profiles of 91 essential oils and 2 absolutes (jasmine) are presented. Both commercial oils (from a large dataset of over 6,300 analyses performed by one of us [Erich Schmidt]) and laboratory-produced essential oils (which can differ considerably in their qualitative and quantitative composition) are discussed.

2.2 WHAT ARE ESSENTIAL OILS?

An essential oil is defined by the International Organization for Standardization (ISO) as a product obtained from a natural raw material of plant origin, by steam distillation (which includes hydrodistillation), by mechanical processes from the pericarp (peel) of citrus fruits, or by dry distillation, after separation of the aqueous phase—if—any by physical processes (11). Essential oils may undergo physical treatments, if they do not result in any significant change in their composition, such as filtration, decantation or centrifugation. For essential oils obtained by steam-distillation, which is the usual production method for most commercial oils, there is a separate definition: essential oil which is obtained by steam distillation with addition of water to the still (hydrodistillation) or without addition of water to the still (directly by steam) (11). Citrus oils (bergamot, grapefruit, lemon, mandarin, tangerine, sweet orange, bitter orange) are so-called cold-pressed essential oils; they are obtained by mechanical processes from the peels of the fruit of a citrus. Essential oils should come from one clearly defined plant source and species; breeding, cultivation and harvest must be optimized, production has to be done according to GMP (Good Manufacturing Practices) (28), and they have to fulfill the requirements as laid down in relevant ISO standards.

Modification of essential oils after production

Sometimes, essential oils undergo one or more physical processes (post-treatment) to alter their chemical composition; these are called post-treatment essential oils. One such treatment is fractional distillation (in this situation called rectification), resulting in rectified oils. The objective of post-treatments can be to eliminate certain individual chemicals (e.g., phototoxic furocoumarins [psoralens] from bergamot oil, methyl eugenol from rose oils), lower the concentration of certain fractions, such as the terpenes or sesquiterpenes by rectification (terpeneless essential oil, terpeneless and sesquiterpeneless essential oil), to concentrate one or more chemicals (concentrated or folded essential oils) or change the color of the essential oil. Reducing the amount of the monoterpenes limonene, γ-terpinene, α- and β-pinene and terpinolene, for example, results in a – desired – higher concentration of 1,8 cineole in eucalyptus oil. Especially citrus oils undergo treatments of concentration by rectification. The main objective here is to *reduce* the concentration of limonene because of its bitterness and limited solubility in flavor preparations, and to *increase* the amounts of C_7-C_{12} fatty aldehydes, citral and further minor components including α-terpineol, citronellol, nerol, linalool, linalyl acetate, geraniol, geranyl acetate and neryl acetate.

2.3 PRODUCTS OBTAINED FROM PLANTS WHICH ARE *NOT* ESSENTIAL OILS

In older literature, but still today, both in the lay press and in scientific literature, the term essential oil is often incorrectly used for a variety of products obtained from plant material by methods other than distillation or cold-pressing, e.g., by solvent extraction, supercritical fluid extraction (which is a well-accepted method to produce highly sophisticated solvent-free products for the flavor industry) or simultaneous distillation and extraction. Reports of essential oils that were extracted are by definition wrong. Examples of other products obtained from plant material which are *not* essential oils include the following.

Absolutes are products obtained from concretes, resinoids, supercritical fluid extracts or pomades by extraction with ethanol. These products contain not only fragrance compounds, but also fatty acids, their methyl esters and paraffins (up to 50% by weight). As these fatty materials do not contribute to the fragrance but do cause solubility problems (perfumes in winter may become cloudy when cooling off), they have to be removed, which is done by solubilizing in a large excess of ethyl alcohol. The solution is then cooled to below 5°C and filtered to eliminate the precipitated waxes. After removing the ethyl alcohol by distillation and thereafter concentration of the solution by vacuum distillation, a product remains an absolute. This product contains all the fragrance compounds, but still also some fatty materials. These absolutes are the products used in the fragrance industries, of which jasmine absolutes and violet leaf absolutes are prominent examples.

Aromatic waters (synonym: hydrolates) are aqueous distillates which remain after steam-distillation of plant material and removal (separation) of the essential oil. These products (e.g., rose water) are often added to cosmetic products. They differ from essential oils in both composition and concentration of chemicals.

Concretes are products obtained from fresh plant material by extraction with one or more solvents, which are subsequently (partly or totally) removed. Conventional steam-distillation is generally considered unsuitable to process some flowers and other plant material from, for example, jasmine, cassie (*Vachellia farnesiana* (L.) Wight & Arn., fragrant acacia), narcissus, *Osmanthus* species, tuberose and violet leaves, since it induces thermal degradation of many compounds contained in the plant. Therefore, solvents, usually hexane or supercritical fluids such as CO_2, are used to extract the fragrant chemicals. After the solvent has evaporated, a viscose product remains called a concrete.

Extracts are products obtained from plant biomass by treating them with one or more solvents.

Pomades are fragrant products obtained with a very old method using fat. In cold enfleurage (enfleurage à froid) flowers are pressed into a layer of animal fat for diffusion of the odoriferous compounds of the flower in the fat. Flowers can also be immersed in warm melted fat (enfleurage à chaude). Nowadays, pomades are hardly produced anymore because of very high cost.

Resinoids are products obtained by extracting dry plant material, usually gum resins like myrrh or olibanum, with one or more solvents.

These products are not discussed in this book, with the exception of jasmine absolutes. They are of great interest to dermatologists, as there is considerable literature on contact allergic reactions to jasmine absolute.

2.4 HISTORY

The process of distillation may date back to around 5,000 years ago, but its origin is unknown. Some point at China as the cradle of hydrodistillation, while others think it was the Indus culture; some authors credit the Arabs as being the inventors of the technique of distillation (6). There are indications that the art of distillation was already a serious science in ancient Mesopotamia (4). However, no essential oils were produced, but distillation was rather used for alchemy or medicinal purposes, and an important function appeared to be concentration and purification of alcohol. The ancient Egyptians expanded and improved Mesopotamian techniques, largely because of their uses in embalming (4). Transfer of the practice of distillation to the West was brought on by the Crusades. Crusaders returning home brought with them distilled alcohol for extracting plant material, fragrant raw materials and refined glass for the production of distillation equipment. The first documented distilled plant material was rose water (21). Hieronymus Brunschwyk in the 12th century, in his treatise The true art to distil, listed some 25 essential oils produced at that time. However, these essential oils were probably fragrant alcohols or aromatic waters rather than essential oils in the current sense. This age of alchemy brought progress in distilling alcohol and alcohol together with plant material (5). The thirteenth century Arabian writer Ad-Dimaschki also provided a description of the distillation process, and wrote about the production of distilled rose water as well as of a cooling system in the distillation plant.

In the 16th century, the availability of printed books facilitated ‘scientists’ seeking guidance on the distillation of essential oils. At that time, discrimination between volatile oils and odorous fatty oils could be made. In the 19th century, distilling plants was further developed and the procedure was now based on higher knowledge of chemistry and analysis of single components of the distilled products, which by now were real essential oils. The oils were obtained from cultivations of rose and jasmine, but also from medicinal plants, herbs, spices and citrus fruits, growing in the countries around the Mediterranean Sea, such as France, Spain, Italy, Morocco, Tunisia and Egypt. A major development was the invention of industrial scale vessels in France around 1930. These were walled in and fixed, and were heated with wood or the dried, exhausted biomass previously used for essential oil production. However, a source of fresh water had to be there for the cooling unit of the distillation plant. This stimulated the development of the first mobile distillation units. Working near the fields of cultivation or greater natural resources of wild growing plants, long transports to a distillation plant were not necessary and water from brooks or rivers was everywhere in the Provence. This area would soon become the center of improvement of technology for larger production units, which at that time had become necessary to satisfy consumer demand for lavender and lavandin oil. Not only lavender and lavandin were cultivated in the Provence, but also fennel, basil, thyme, sage, clary sage and tarragon. Ships brought spices and exotic plants such as patchouli to France, which were distilled there and prepared for use. The technical improvements spread all over the northern hemisphere to Bulgaria, Turkey, Italy, Spain, Portugal, as well as to northern Africa. A very important chapter in the history of distillation of plant material was the invention of the alambic à bain-marie, technically speaking a double-walled distillation plant. Steam was not only passed through the biomass, but was also used to heat the wall of the still. This new method improved the speed of the distillation as well as the quality of the top notes of the essential oils thus produced. More recently, the distillation process has become computer controlled with many adjustable parameters, leading to the production of high-quality essential oils.

Citrus oils were already produced by manual expression in the 16th and 17th centuries. Real progress was made in the 20th century with the development of machines which would fulfill the requirements for the production of large quantities of citrus essential oils, such as the apparatus for the Pellatrice and Sfumatrice methods of citrus oil production. Before that, peels were manually pressed with wooden or iron tools; juice and oil were captured and separated by centrifugation. At the end of the 19th century and the beginning of the 20th, hundreds of women and men would sit in great halls in Sicily, Italy, working on endless quantities of fruits.

More information on the history of essential oils can be found in ref. 6.

2.5 WHAT ARE ESSENTIAL OILS USED FOR?

Essential oils are an important trade commodity. The 10 essential oils with the highest estimated trade volumes in 2007 were sweet orange oil (51,000 tons), cornmint oil (32,000 tons), lemon oil (9,200 tons), eucalyptus oil (4,000 tons), peppermint oil (3,300 tons), citronella oil (1,800 tons), clove leaf oil (1,800 tons), Chinese sassafras oil (1,800 tons), lime oil distilled (1,800 tons) and lavandin oil (1,200 tons) (1). This is more than 105,000 metric tons (a metric ton is 1,000 kilograms). All other essential oils are traded in smaller quantities, yet they are important, being frequently used in flavors, cosmetics and perfumery. The prices for essential oils depend mainly on the complexity of cultivated plant species, the mode of harvesting (which is sometimes done by hand, e.g., flowers from rose, bitter orange and jasmine) and the yield of oil. The yield varies from 0.01% in the case of orris oil (prepared from the rhizome of *Iris pallida*, which is the most expensive essential oil with a price of around 150,000 USD/kg) up to 40% for wild thyme. Examples of prices for some of the top 10 products are 4.50 USD/kg for sweet orange oil, 50 USD/kg for lemon oil and around 100 USD/kg for peppermint oil. The total value of the essential oils trade amounts to many billions of USD (2).

Essential oils have a wide field of applications; examples are shown in Table 2.1. The largest buyer of essential oils is the flavor industry, making flavors which are widely used by the food, fragrance and cosmetics industries. In the food industry, essential oils and chemicals derived from them are added to a vast array of products including non-alcoholic (fruit juice preparations, flavored waters, many other soft drinks) and alcoholic beverages, and foods (e.g., milk drinks, yoghurt, candies, chocolate, quick meals, baking mixtures, meats, sausages, teas and even spices and herbs) for flavoring purposes. Essential oils may also be added to foods (e.g., to meat) for (longer) preservation and are widely employed by the tobacco industry. Essential oils are also used as masking agents for topical pharmaceutical preparations. Another major application of essential oils is in perfumes (perfume, eau de parfum, eau de toilette, eau de cologne), cosmetics, household products such as detergents, softeners, cleaning products and other consumer commodities including room scents, candles, incense and bouquets (a bouquet is a potpourri existing of dried flowers, barks and leaves, perfumed by adding perfume mixtures supplied separately).

Table 2.2 Concentrations of fragrance chemicals used in finished cosmetic products (12,31)

Product	Concentration range
Perfumes	
Eau de cologne	3-7%
Eau de parfum	12-15%
Eau de toilette	7-12%
Extrait	up to 30%
Perfume	18-25%
Splash cologne	1-3%
Leave-on cosmetics	
Body creams	0.1-0.3%
Creams	0.05-0.4%
Deodorant cream	0.5-0.8%
Deodorant spray	0.1-0.5%
Deodorant stick	0.8-1.0%
Fragrancing cream	0.5-1.5%
Hair deodorant	0.02-0.05%
Hair styling aid	0.05-0.2%
Lipstick	0.005-0.03%
Lotions	0.4-1.2%
Rinse-off products	
Bar soap	1-7%
Bath salt	0.2-0.4%
Bubble bath	0.8-1.5%
Conditioner (hair)	0.1-0.3%
Face cleansers	0.02-0.06%
Liquid soap	0.2- 0.5%
Shampoo	0.1-0.3%
Shaving creams and gels	0.2-0.4%
Shower gel and body washes	0.5- 1.0%

Essential oils and fragrance chemicals are often incorporated to give the desired scent to cosmetics products. However, they are also employed as masking fragrance. Certain ingredients of cosmetics, such as fatty acids, lipid balancing bases, aqueous plant extracts, fatty oils and surfactants, have an inherent smell. To mask this, an efficient and suitable perfume composition is added to these products. All cosmetics can be presumed to contain fragrances, unless they are specifically labeled as ‘fragrance-free’, ‘contains no perfume’, ‘non-scented’ or have similar indications. However, even then, they may sometimes contain (masking) fragrance materials (29). Approximate concentrations of fragrances in perfumes and cosmetics are shown in Table 2.2. In general,

Table 2.1 Examples of essential oil applications

Flavor industry: flavors for the food industry
Food industry: soft drinks, foods, alcoholic beverages, spices, herbs, tea, food preservation
Fragrance industry: perfumes, fragrances for other products
Cosmetics industry
Household products: detergents, softeners, room scents, candles, incense
Tobacco industry: cigarettes
Medicinal use: folk medicine, traditional medicine, phytotherapy, balneotherapy, aromatherapy
Pharmaceutical industry: masking agent
Animal food

fragrances contain between 5 and 10% of essential oils. Most commonly used are orange, bergamot, lemon, lavender, patchouli and cedarwood oils. Spice oils are employed in small concentrations and others in traces. Expensive oils are only used in fine fragrances.

Essential oils are also widely employed to promote health and combat diseases, e.g., in forms of traditional and folk medicine, phytotherapy (the use of extracts of natural origin as medicines or health-promoting agents) and aromatherapy. Aromatherapy, which appears to be gaining in popularity, has been defined by aromatherapy and essential oils book authors as 'The therapeutic application of essential oils and aromatic plant extracts in a holistic context, to maintain or improve physical, emotional and mental well-being' (25), 'the use of essential oils, applied topically, orally, by inhalation or by other means, to promote health, hygiene and psychological wellbeing' (30) or - briefly - 'the therapeutic use of essential oils' (26).

Essential oils are also used in animal feeding (32). They may be employed as appetizer and for preservation purposes, as certain essential oils that contain high concentrations of carvacrol such as origanum and thyme oil have been shown to have antimicrobial effects (10). Herbs and essential oils may, according to some authors, even be able to partly substitute for antibiotic growth promoters (33).

2.6 PRODUCTION OF ESSENTIAL OILS

Biomass for production of most essential oils can grow in various countries and on more than one continent. Successful cultivation depends inter alia on the climate, soil, stress by insects, and water. For most plants, a warm climate with sufficient rain or water supply benefits high-quality crops. A balanced content of mineral elements (fertilizing) benefits the growth of the plants and the content of essential oil. Stress by insects will lead to higher oil yield, as the oil is used as a repellent by the plant. Some plants can grow only in higher areas, e.g., lavender in France (above 800 meters) and certain herbs in the Himalayas. For sufficient crops of herbs and spices, ample exposure to sunlight is necessary. Several Asian countries, e.g., India, benefit from their sunny climate and plants can be harvested two or sometimes three times per year. More information on these aspects can be found in ref. 6.

To produce high-quality commercial essential oils, the biomass should be perfect and the production method optimal. Most essential oils are produced by steam-distillation, but citrus oils are obtained by expression methods. For many crops, it is very important that distillation takes place very soon after harvesting. Melissa, for example, will start withering shortly after being cut; for these plants, field distillation, where harvested plants are immediately placed in the distillation vessel and distilled in situ, can best be used. The same applies to the production of rose essential oils. The rose petals have to be picked very early in the morning, when the essential oil yield is at its highest level; distillation takes place until noon. Another important feature in essential oils production is adequate pre-distillation biomass preparation. Drying will increase the yield of oil, as a larger volume of biomass can be processed; it also saves energy. Some plants have to be dried to result in a perfect quality essential oil, e.g., in the cases of cinnamon, orris and vetiver. Fruits and seeds need to be ground to guarantee complete exhaustion of the oil present in the plants during distillation, for example, pepper, pimento, coriander, anise and fennel. Chipping is necessary when distilling wood and heartwood (e.g., cedarwood, cypress, rosewood). In the case of sandalwood oil, the wood even needs to be pulverized. Most herbs are cut into smaller pieces before distillation. This is usually already done automatically on the field by the harvesting equipment; the biomass is then loaded into containers, which can be connected to a steam source and cooling unit in the distillation plant. Shortly before the harvest, a few kilograms of biomass are steam-distilled and analyzed by GC/MS to determine at what timeframe the harvest results in optimal composition of the oil. More information on these aspects can be found in ref. 6.

Distillation methods

There are two methods of distillation: steam-distillation and water-steam distillation. In the steam-distillation method, there is a direct supply of steam to the biomass. The distillation apparatus consists of a still pot (kettle) containing the biomass, a cooling system (condenser), an oil separator and a high-capacity steam generator. The still pot looks like a cylindrical vertical storage tank and has steam pipes located at the bottom. The biomass is placed on multiple perforated plates resembling sieves located over each other; this separates the plant material, prevents compaction and allows the steam unimpeded access to the biomass. The walls of the oil-bearing plant cells are destroyed by pressure and heat, and volatile chemicals are set free. The oil-laden steam leaves the kettle through an outlet in the still pot lid and enters the alambic. This is the head of the distillation plant and here the vaporous mix of water and oil starts to condense. The steam is then passed through the cooling system, which is either a plate heat exchanger or a surface heat exchanger, such as a cold-water condenser. The condensate is subsequently separated into essential oil and distillation water in an oil separator, e.g., a Florentine flask. The distillation water is sometimes redistilled and the essential oil dried and stored (6).

The water-steam distillation method is used mostly for rose oil production. Here, water is present in the double-walled vessel, and the water contains the biomass. The water plus biomass is heated by steam, which is led through the walls of the still. When the water starts to boil, steam is liberated containing the volatiles. The rest of the procedure is identical to steam-distillation, described above.

Currently, distillation is a computer-controlled process with programmed parameters, which include steam quantity, temperature, speed of heating and the pressure of the steam flowing through the vessel. These parameters can vary during the distillation process. Usually, steam-distillation is performed under slightly higher than atmospheric pressure. Some oils like cistus oil and some conifer oils are distilled with superheated steam, at a temperature higher than its vaporization point (around 105°C) to increase the yield and enrich the oil with a higher quantity of high boiling components. The size of the vessel is also an important factor. Most vessels have a capacity of 4 tons or higher. For the production of some oils, such as pepper and orris oil, however, smaller vessels are needed, as the biomass has to be stirred during the distillation process to prevent accretion to the wall, which results in burning. For the production of most oils, steel or iron vessels are used. However, sometimes glass is preferred to avoid any reaction with iron particles. More information on these aspects can be found in ref. 6.

Production of citrus essential oils

A very important category of essential oils is the citrus oils, obtained from citrus fruits of the Rutaceae family. The main fruits are sweet orange, lemon, bergamot, lime, bitter orange, mandarin and grapefruit. Their oil cells are located in the epicarps (outermost layer of the peel, the pericarp), and their smell can be released by scratching or cutting. All citrus oils are prepared by expression of the pericarps with one exception: lime oil can be produced by both expression and distillation, which results in two oils differing in composition, smell and flavor. Distillation for other citrus oils is impossible, as heating will destroy important but unstable molecules, such as fatty aldehydes. These chemicals are also unstable when in contact with acids (from the fruit juice) and therefore the oil from the peels should be removed in a way that such contact is avoided.

Three important methods are used: the Sfumatrice method, the Pellatrice method and the FMC method (Food Machinery Corporation), also called the brown method. In the Sfumatrice method, the fruits are cut in half and the endocarp (the flesh) is removed. The peel then is squeezed in the Sfumatrice machines and the mixture of oil, water and juice is decanted and the oil phase later separated by centrifugation. The Pellatrice method uses spiked Archimedes screws to bruise the oil cells in the epicarp and initiate the flow of oil. The peel oil is washed out by a permanent water spray and then is filtered and centrifuged. The FMC process is designed for the processing of large quantities of fruits. It is a combination of juice pressing and peel pressing. Through a hole in the bottom of the fruit, cut by a knife, a tube is placed within the fruit. By pressing each single fruit, juice runs through the tube and is led to a separate system. At the same time, the epicarp is also pressed and the oil will run outside the fruit in a separate tube, thus avoiding contact between the (acid) juice and the oil. The oil from the oil–water emulsion pressed from the peels is separated by centrifugation. More information on these procedures can be found in ref. 6.

The last process to produce essential oils is the so-called dry distillation, which applies to distillation of wood, barks, roots or gums, without addition of water or steam (11). Without the supply of oxygen, this process is in fact a form of carbonizing. The chemicals that emerge from the biomass are mainly phenolic compounds that have a leathery odor. An example of a dry-distilled essential oil is birch tar oil, which was formerly used in perfumery. Because of toxicity issues, however, it is no longer used in this application. More information can be found in ref. 6.

2.7 CHEMISTRY OF ESSENTIAL OILS

Essential oils are multi-component mixtures; in individual oils, up to 400 chemicals or even more may be identified when sophisticated analytical equipment and the proper detection methods are used. In mass spectra databases, over 5,500 entries for chemicals can be found, of which more than 3,000 may be present in essential oils. The largest group of chemicals found in essential oils consists of terpenes. Terpenes are hydrocarbon chemicals produced from five-carbon isoprene units (C_5H_8). From these units, numerous molecules can be constructed in biosynthesis, both linear-chained chemicals and molecules with one or more ring structures. There are several classes of terpenes based on their number of isoprene units; in essential oils, the most important ones are the monoterpenes and the sesquiterpenes. Monoterpenes possess 10 carbon atoms and are built from two isoprene units ($C_{10}H_{16}$) which can form various carbon skeletons. There are three forms of monoterpenes: linear (acyclic), monocyclic and bicyclic. Sesquiterpenes possess 15 carbon atoms; they are built from three isoprene units ($C_{15}H_{24}$) and may occur in acyclic, monocyclic, bicyclic and tricyclic forms. These are the terpenes with higher boiling temperatures. Mono- and sesquiterpenes are the main components in essential oils, sesquiterpenes comprising about 25% of the terpene fraction. Volatility and the typical odor of essential oils are created through both groups. Chemical modification of terpenes and sesquiterpenes, e.g., by rearranging carbon skeletons or by oxidation, produces compounds generally termed terpenoids. The oxidation products are the most important, creating subgroups like alcohols, aldehydes, phenols, ethers and ketones. Infrequently, during biosynthesis, functional groups like sulfur or nitrogen are bond to or integrated in the carbon skeleton.

The most important chemical classes and some examples of compounds belonging to the various groups found in essential oils are shown in Table 2.3. Also shown is the number of oils/absolutes in which they were present in a group of 91 oils and two jasmine absolutes analyzed by one of us (ES) between 1998 and 2014 (total of nearly 6,400 samples) and the oils/absolutes containing the chemicals in the highest concentrations.

2.8 FACTORS INFLUENCING THE COMPOSITION OF ESSENTIAL OILS

The composition of essential oils can vary considerably from country to country, from producer to producer, and even from year to year for the same producer and crop. Factors that may influence the oils' chemical composition are shown in Table 2.4. Important parameters

Table 2.3 Chemical classes, examples of compounds, and data on their presence in essential oils/absolutes (34-37)

Chemical class and important chemicals	Nr. oils[a]	Oils / absolutes with highest concentrations
Acyclic terpenes		
Myrcene	73	Rosemary (46.0%), bay (32.0%), dwarf pine (30.2%), juniper berry (21.6%)
(*E*)-Ocimene	51	Melissa (9.3%), neroli (9.3%)
(*Z*)-Ocimene	1	Bay (0.1%)
Monocyclic monoterpenes		
p-Cymene	66	Black cumin (57.5%), thyme (25.7%), Spanish thyme (25.4%)
α-Fenchene	10	Valerian (4.0%), thuja (1.4%), spike lavender (1.0%)
Limonene	84	Sweet orange (95.7%), bitter orange (95.5%), grapefruit (95.5%)
β-Phellandrene	47	Elemi (23.9%), angelica root (22.0%), black pepper (17.4%)
α-Terpinene	50	Tea tree (11.7%), marjoram (10.3%), ravensara (8.2%)
γ-Terpinene	66	Marjoram (50.2%), tea tree (23.0%), thyme (21.2%)
Terpinolene	65	Tea tree (45.7%), dwarf pine (8.3%), marjoram (6.8%)
Bicyclic monoterpenes		
Camphene	59	Pine needle (27.4%), valerian (24.1%), silver fir (17.3%)
δ3-Carene	33	Dwarf pine (34.4%), cypress (25.9%), black pepper (17.6%)
α-Pinene	81	Cypress (68.0%), juniper berry (66.6%), olibanum (46.5%)
β-Pinene	73	Galbanum resin (81.2%), silver fir (31.7%), dwarf pine (29.0%)
Sabinene	61	Nutmeg (36.7%), ravensara (25.5%), juniper berry (17.7%)
α-Thujene	48	Olibanum (ex *Boswellia serrata*) (65.3%), thyme (25.9 %), olibanum (ex *Boswellia sacra*) (25.8%)
Tricyclic monoterpenes		
Tricyclene	22	Pine needle (2.7%), silver fir (2.6%), juniper berry (2.0%)
Acyclic sesquiterpenes		
α-Farnesene	8	Melissa (9.1%), ginger (5.7%), citronella Sri Lanka (4.6%)
(*E*,*E*)-α-Farnesene	15	Ylang-ylang third (28.9%), ylang-ylang second (19.7%), ylang-ylang extra (10.3%), cananga (7.1%)
(*E*)-β-Farnesene	23	Chamomile German (35.4%), lavender (4.5%), spike lavender (4.3%)
Monocyclic sesquiterpenes		
α-Bisabolene	4	Carrot seed (2.9%), chamomile German (2.7%), spike lavender (1.5%)
β-Bisabolene	22	Carrot seed (7.8%), ginger (6.3%), black pepper (5.9%)
Curcumene	12	Ginger (5.8%), costus root (2.3%), valerian (1.8%)
β-Elemene	41	Myrrh (8.7%), costus root (7.7%), basil (5.5%), melissa (4.7%)
α-Humulene	60	Sage Dalmatian (12.4%), cananga (9.4%), myrrh (8.8%)
α-Zingiberene	4	Ginger (17.0%), black pepper (1.2%), aniseed (0.5%)
Bicyclic sesquiterpenes		
α-Cadinene	2	Myrrh (2.2%), cananga (0.4%)
γ-Cadinene	25	Pine needle (5.3%), hyssop (2.9%), vetiver (2.8%)
δ-Cadinene	55	Cananga (6.1%), ylang-ylang third (5.6%), ylang-ylang second (4.6%), calamus (4.4%)
β-Caryophyllene	85	Cananga (38.0%), black pepper (32.4%), melissa (29.4%), ylang-ylang second (19.5%)
β-Selinene	11	Costus root (4.2%), black pepper (3.2%), carrot seed (3.0%)
Valencene	2	Vetiver (1.9%), sweet orange (0.1%)
Tricyclic sesquiterpenes		
Aromadendrene	10	Tea tree (2.0%), eucalyptus (1.8%), thyme (0.8%)
β-Bourbonene	18	Hyssop (2.4%), myrrh (2.1%), spearmint (1.7%)
α-Cedrene	8	Cedarwood China (38.4%), cedarwood Virginia (27.2%), cedarwood Texas (21.3%)
β-Cedrene	6	Cedarwood China (8.2%), cedarwood Virginia (7.7%), cedarwood Texas (5.2%)
α-Gurjunene	11	Myrrh (3.8%), niaouli (2.8%), tea tree (2.8%)
β-Gurjunene	4	Valerian (0.9%), calamus (0.8%), hyssop (0.3%)
α-Patchoulene	1	Patchouli (8.0%)
β-Patchoulene	2	Patchouli (4.1%), guaiacwood (0.5%)
α-Santalene	8	Sandalwood New Caledonia (6.5%), sandalwood Australia (4.9%), sandalwood (1.9%)
Viridiflorene	4	Tea tree (2.1%), niaouli (2.1%), sage Dalmatian (0.2%)

Table 2.3 Chemical classes, examples of compounds, and data on their presence in essential oils/absolutes (34-37) (*continued*)

Chemical class and important chemicals	Nr. oils[a]	Oils / absolutes with highest concentrations
Acyclic monoterpene alcohols		
Citronellol	15	Geranium (49.4%), rose (44.8%), citronella Java (13.5%)
Geraniol	40	Palmarosa (86.9%), citronella Sri Lanka (48.7%), geranium (31.8%)
Lavandulol	6	Lavender (2.4%), lavandin grosso (1.2%), lavandin abrial (0.2%)
Linalool	74	Rosewood (88.4%), coriander fruit (81.2%), thyme (68.5%)
Nerol	25	Melissa (16.2%), rose (11.0%), ravensara (1.7%)
Acyclic monoterpene esters		
Citronellyl acetate	12	Thyme (17.5%), citronella Java (4.5%), melissa (3.9%)
Geranyl acetate	40	Thyme (21.8%), carrot seed (12.9%), palmarosa (12.5%)
Linalyl acetate	22	Clary sage (64.2%), petitgrain bigarade (54.0%), lavender (43.3%)
Neryl acetate	20	Melissa (2.9%), petitgrain bigarade (2.8%), neroli (2.0%)
Terpinyl acetate	17	Laurel leaf (12.0%), Spanish sage (9.0%), cajeput (3.5%)
Acyclic monoterpene aldehydes		
Citronellal	15	Eucalyptus citriodora (84.4%), citronella Java (49.6%), citronella Sri Lanka (12.0%)
Geranial	22	Lemongrass West India (46.3%), lemongrass East India (46.3%), litsea cubeba (42.3%)
Neral	19	Lemongrass East India (35.5%), litsea cubeba (34.5%), lemongrass West India (33.3%)
Monocyclic monoterpene alcohols		
(*Z*)-Carveol	3	Spearmint (2.0%), olibanum (0.2%), elemi (0.05%)
Menthol	5	Peppermint (47.9%), geranium (2.3%), spearmint (2.2%)
Pulegol	4	Peppermint (1.1%), citronella Java (0.9%), melissa (0.6%)
Terpineol	71	Ravensara (14.7%), cajeput (11.6%), niaouli (9.2%)
Monocyclic monoterpene phenols		
Carvacrol	4	Thyme (77.8%), black cumin (5.8%), olibanum (0.1%)
Eugenol	23	Clove bud (90.4%), clove stem (90.1%), clove leaf (89.1%)
Thymol	5	Thyme Spanish (56.2%), thyme (47.8%), black cumin (2.2%)
Monocyclic monoterpene ketones		
Carvone	10	Spearmint (82.3%), peppermint (0.9%), olibanum (0.6%)
Menthone	5	Peppermint (38.5%), geranium (2.3%), melissa (2.1%)
Piperitone	4	Peppermint (5.4%), spearmint (0.6%), basil (0.06%)
Pulegone	1	Peppermint (5.4%)
Bicyclic monoterpene alcohols		
Borneol	39	Citronella Sri Lanka (7.6%), sage Spanish (7.0%), rosemary (6.3%)
Myrtenol	7	Galbanum resin (2.2%), hyssop (2.1%), olibanum (1.3%)
Pinocarveol	5	Hyssop (19.2%), olibanum (3.2%), laurel leaf (0.1%)
Verbenol (*cis*- and *trans*-)	13	Litsea cubeba (1.8%), angelica root (1.2%), melissa (0.9%)
Bicyclic monoterpene aldehydes		
Myrtenal	8	Galbanum resin (1.2%), chamomile Roman (0.8%), hyssop (0.7%)
Bicyclic terpene ketones		
Camphor (α-, *d*- and *dl*-)	31	Sage Spanish (36.0%), spike lavender (35.1%), rosemary (24.2%)
Fenchone	3	Thuja (16.7%), basil (0.7%), dwarf pine (0.06%)
Monocyclic sesquiterpene alcohols		
Bisabolol (α-, β-, γ-)	15	Chamomile German (38.3%), sandalwood Australia (12.8%), zdravetz (2.8%)
Elemol	19	Elemi (22.1%), citronella Java (7.0%), hyssop (1.9%)
Lanceol	3	Sandalwood oils (3.3%-15.2%)
Bicyclic sesquiterpene alcohols		
Cadinol (α-, δ- and τ-)	27	Basil (7.1%), vetiver (3.5%), ylang-ylang third (2.6%)
Chrysanthemol	1	Chamomile German (0.1%)
Eudesmol (α-, β-, γ-, 10-epi-γ-)	22	Geranium (5.6%), zdravetz (5.3%), guaiacwood (4.7%)
Muurolol (α- and τ-)	11	Ylang-ylang second (2.0%), cananga (1.8%), melissa (1.2%)

Table 2.3 Chemical classes, examples of compounds, and data on their presence in essential oils/absolutes (34-37) (*continued*)

Chemical class and important chemicals	Nr. oils[a]	Oils / absolutes with highest concentrations
Bicyclic sesquiterpene aldehydes		
Isovalencenal	–	
Zizanal	–	
Bicyclic sesquiterpene ketones		
Germacrone (*E*,*E*-)	1	Zdravetz (66.6%)
Khushimone	1	Vetiver (3.3%)
Nootkatone	4	Grapefruit (0.4%), vetiver (0.3%), bitter orange (0.05%)
Valeranone	1	Valerian (4.0%)
α-Vetivone	1	Vetiver (6.1%)
β-Vetivone	1	Vetiver (5.7%)
Tricyclic sesquiterpene alcohols		
Patchoulol	1	Patchouli (33.9%)
α-Santalol	3	Sandalwood oils (42.9%-53.3%)
β-Santalol	3	Sandalwood oils (17.7%-23.6%)
Viridiflorol	5	Niaouli (22.6%), Dalmatian sage (2.7%), tea tree (0.8%)
Aromatic alcohols		
Benzyl alcohol	8	Jasmine sambac (6.3%), jasmine (3.7%), ylang-ylang extra (0.3%)
Cinnamyl alcohol	3	Cassia (0.4%), jasmine sambac (0.2%), cinnamon leaf (0.08%)
2-Phenethyl alcohol	4	Rose (2.7%), Jasmine sambac (1.2%), cassia (0.7%)
Aromatic esters		
(*Z*)-Methylcinnamate	1	Basil (23.6%)
Methyl salicylate	8	Jasmine (2.8%), Jasmine sambac (1.6%), clove bud, clove leaf and clove stem (each 0.3%)
Aromatic aldehydes		
Benzaldehyde	7	Cassia (2.3%), niaouli (1.8%), cinnamon bark (1.0%)
Cinnamic aldehyde ((*E*)-, (*Z*)-)	5	Cassia (83.1%), cinnamon bark (72.7%), cinnamon leaf (2.8%)
Cuminaldehyde	–	
Vanillin	–	
Phenolic ethers		
(*E*)-Anethole	8	Aniseed (98.6%), star anise (90.1%), black cumin (0.9%)
(*Z*)-Anethole	2	Star anise (0.4%), aniseed (0.3%)
Methyl chavicol (estragole)	14	Basil (87.0%), ravensara (19.9%), star anise (5.9%)
Safrole	4	Ravensara (2.0%), nutmeg (1.8%), cinnamon leaf (1.3%)
Oxides		
Bisabolol oxide A	1	Chamomile German (46.0%)
Bisabolol oxide B	1	Chamomile German (12.1%)
1,8-Cineole	44	Eucalyptus (88.7%), cajeput (70.2%), ravensara (68.0%), niaouli (61.2%)
Linalool oxide (*cis*-, *trans*-, furanoid, pyranoid)	37	Rosewood (2.1%), coriander fruit (1.4%), geranium (1.0%)
Menthofuran	1	Peppermint (7.0%)
Acids		
Geranic acid	1	Litsea cubeba (0.1%)
Isovaleric acid	1	Valerian (2.4%)
Zizanoic (khusenic) acid	1	Vetiver (4.3%)

[a] number of essential oils / jasmine absolutes in which the chemicals have been identified, in a group of 91 essential oils and two jasmine absolutes investigated between 1998 and 2014 (nearly 6,400 samples investigated)

Table 2.4 Factors that may influence the chemical composition of essential oils[a]

Plant parameters
Species
Cultivar or variety
Chemotype
Age of plant
Cultivated or wild plants

Environmental parameters
Origin of plant
Climate: temperature, rain, sun, altitude
Soil conditions
Fertilization
Use of herbicides, pesticides
Water supply or water stress
Insect stress
Monocultures or interbreeding with other species
Presence of weeds (especially bio culture)

Harvest and post-harvest / pre-distillation parameters
Plant part or plant parts used
Season of harvest
Year of harvest
Number of harvests per year
Pretreatment of biomass (fresh, dried, particle size, mode of drying [sun, shade, oven], drying time)
Storage conditions of source plant material and storage time
Weeds unintentionally harvested with essential oil source species (amount, species)

Production parameters
Mode of production: steam-distillation, hydrodistillation, steam/hydrodistillation, cold-pressing (citrus oils)
Distillation parameters: temperature, flow, pressure, distillation time, fractional distillation
Commercial oil or laboratory-produced in Clevenger-type apparatus
Rectification (see Modification of essential oils after production)
Adulteration with natural materials or synthetic chemical compounds
Inadequate removal of capture solvents (laboratory-prepared oils)

Other parameters
Storage condition of essential oils
Storage time of essential oils
Age of essential oil
Aging: exposure to oxygen and ultraviolet light
Analytical equipment used, accuracy of analysis, availability of mass spectra libraries, automated software

[a] examples. The table is not meant to be exhaustive.

are those related to the plant (species, cultivar, variety), to the environment (climatic and soil conditions, water, fertilization), to harvest and post-harvest conditions (part of the plant harvested, season, mode and duration of storage and pre-distillation treatments such as drying), to the mode of production (differences between laboratory-produced oils and large-scale commercial steam-distilled essential oils) and other factors, of which the analytical procedures used to identify the composition qualitatively and quantitatively are very important.

Various plant species are known to have several so-called chemotypes. A clear and widely accepted definition for this well-known phenomenon is lacking. In practice, it means that, within a population of one plant species with the same morphological features, groups exist with different composition of their secondary plant products. This is probably regulated by one or only a few genes (13). The oils produced from the various genotypes are qualitatively very similar, i.e., they contain the same spectrum of chemicals, but there are major differences in the quantities of one or several of these. Thus, a specific chemical may be absent or present in trace quantities in one chemotype and be the dominant component in concentrations of >50% in another. In 25 commercial thyme oils from *Thymus vulgaris*, for example, the following ranges in concentrations were observed for the major components: carvacrol trace-77.8%, linalool 0.03-68.5%, thymol 0.2-47.8%, 1,8-cineole 0.2-36.5%, *cis*-sabinene hydrate 0.07-32.7% and geraniol 0-26.0% (Chapter 5.85). The chemotypes are usually assigned on the basis of single dominant chemicals (the compound with the highest concentrations) or a few major components in essential oils, although this method may well be criticized (14,16). Corroboration of chemotypes by genetic coding has not been done. In fact, the term 'chemotype' is applied rather loosely by various authors, and some suggested they had found a new chemotype on the basis of one laboratory-hydrodistilled oil containing an unusual dominant chemical. Plant species that produce oils with several chemotypes include thyme (both from *Thymus vulgaris* [3,15, Chapter 5.85] and from *Thymus zygis* [Chapter 5.86]), *Melaleuca alternifolia* (tea tree oil, Chapter 5.83), rosemary (Chapter 5.72), and ravensara (Chapter 5.71).

The mode of production also heavily influences the composition of essential oils. Thus, laboratory-prepared oils, which are produced with a Clevenger-type apparatus, in which the biomass is cooked in boiling water, show major differences from the same oils produced in large industrial plants with steam-distillation. Long distillation times may alter the quality of odor and the whole composition. Plant parts used in scientific studies are often carefully selected and totally clean of any byproducts. Thus, when only the flowers from lavender are hydrodistilled in a Clevenger apparatus, it will often contain no coumarin. In industry, several centimeters of stalks remain with the flowers after harvesting and these contain coumarin. Other byproducts may also influence the composition. In conventional culture, herbicides are used to combat weed. In the bio culture, however, such products are forbidden and, consequently, weeds can grow excessively. As a result, organically produced plant material can include up to 30% extraneous herbs and weed, which can change the composition of the oil. Some weeds contain acids, which can react with free alcohols generated by the basic biomass. In the case of lavender, for example, this may result in higher values of lavandulyl acetate and linalyl acetate. The use of higher pressure in commercial steam-distillation of biomass such as wood, root and plants containing resins results in higher values of sesquiterpenes. The composition of the oil, or actually its *reported* composition, also depends on the analytical procedures performed. For the industry, determining concentrations down to 0.01% for individual chemicals is usually sufficient. In scientific publications, it is often tried to identify chemicals in lower concentrations also.

2.9 ANALYSIS OF ESSENTIAL OILS

The analysis of essential oils has made tremendous progress in the last 35 years. In the early years of analytical chemistry, analytical assays were simple, with chemical reaction methods to detect single components. Isolation of the compound by separation through distillation was helpful for its recognition. Reaction experiments gradually improved and other tests including gravimetric analysis, photometry and titration were soon standard. With the invention gas-chromatography, a huge step was taken forward in identifying chemicals not only qualitatively, but also their quantities. Today this method is highly sophisticated and is performed in every good laboratory. Currently, in essential oil chemistry, several tests are used to determine the chemical composition of essential oils and to verify their naturalness.

Organoleptic methods are still very important. The human nose is able to detect some molecules in traces and even a few parts per million (ppm) in air, whereas analytical equipment has to be very finely adjusted to get proper results. Vanillin and maltol are examples of such chemicals as are sulfuric compounds like *p*-menthanone-3-thiol, which gives black currant its typical odor. Essential oils are always checked olfactorily, even when analytical results confirm their identity and naturalness, as odor is still their most important quality! Appearance and color are also important factors for commercial use. Citrus fruits can vary widely in color depending on the time of harvesting. Clementine oil produced from fruits at the beginning of the ripening stage is pale yellowish or orange and gradually changes to orange or orange-red when riper fruits are used. A constant color is a precondition (consumer demand) for use of essential oils in cosmetics as well as for food flavors.

Physicochemical test methods are widely used in the chemical industry. Currently, these tests are all automated; connectivity with databases ensures the standard of quality. To obtain full essential oils quality control, the following parameters are established and tests performed: relative density, refractive index, solubility tests and determination of evaporation residues (to rule out adulteration with fatty or high boiling substances). Also helpful are older methods such as phenol content, carbonyl value, ester and saponification value and the content of free and total alcohol.

Essential oils are often analyzed with chromatographic methods, e.g., thin layer chromatography (TLC), a fast and inexpensive method for identifying substances and testing the purity of compounds. The principle of chromatography is based on the distribution of the constituents to be separated between two immiscible phases, the stationary phase with a large surface area and a mobile phase that ascends through the stationary phase by capillary forces. A glass plate covered with a thin layer of adsorbent (usually silica gel or alumina) is used as the stationary phase. One drop of essential oil is applied near its edge. The plate is then positioned in a developing chamber with one end immersed in the developing solvent, which is the mobile phase. When the mobile phase with the oil constituents has reached about two-thirds of the plate length, the plate is removed, dried, and the separated components are located. In some cases the spots are directly visible; others must be visualized (colored) by the application of a solution of iodine or sulfuric acid, or with the aid of ultraviolet light. Identification of chemicals is based on the calculation of the so-called ratio of fronts (Rf) value for each spot (38).

Gas chromatography (GC) is also based on the principle of separation of chemicals using a stationary and a mobile phase. A carrier gas is used to transport small amounts of essential oil within the gas phase through a column at a constant speed. In general, essential oil GC analyses are carried out on 25-50 meter columns, with 0.20-0.32 mm internal diameters, and 0.25 µm stationary liquid phase film thicknesses. By constant or rising temperature in the oven, in which the column is placed, and permanent absorption and desorption of the oil components between liquid and mobile (gas) phase, separation of the various components of the oil is enabled. After reproducible times (retention time, RT) the various components reach the outlet of the column and are registered by the flame ionization detector

(FID). Components are burned by a small hydrogen flame using synthetic air (to avoid misinterpretation by polluted environmental air), whereby a signal is recorded that generates a chromatogram, which is a signal versus time graphic (19). The chromatogram contains information for both qualitative and quantitative analysis of the essential oil (39). The peak area and height are a function of the amount of chemical present. The identity of the compounds is determined by the retention time. Unfortunately, several chemicals can have the same retention time, which necessitates increasing separation performance. In addition, confirmation of the identification based on the retention time by other tests is necessary.

After mass spectrometry (MS) was invented, gas chromatography coupled with MS (GC-MS) soon became the standard procedure for analyzing essential oils. In mass spectrometry, molecules are bombarded with ions under vacuum and high-temperature conditions. This generates charged molecules or molecule fragments, of which mass-to-charge ratios are determined, supplying a unique fingerprint ('mass spectrum') for the chemical. Mass spectra are stored in databases, of which several are commercially available (40-42). These libraries can also be self-established by numerous runs with molecules of highest purity. In GC-MS, spectra of chemicals are automatically compared by computer with their retention time or index, which results in a correct allocation and identification of the chemicals

A revolution was the development of two-dimensional GC with time of flight MS (GCxGC-TOF-MS). Very often, in spite of using high-quality separation equipment, different molecules elute (leave the column) in very small time frames and therefore cannot be reliably separated (co-elution). In this new method, two columns are used, which are connected. The system for comprehensive two-dimensional GC takes every peak (component) and slices small cuts, before transferring them to the second column, which works 50 times faster than the first column. A fast detector collects the data at a rate of 100 Hz (Hertz, cycles per second) or more. This results in a plot picture showing a three-dimensional display or bird's eye view of the substances identified. An ordinary mass spectra unit is equipped with an acquisition rate of only 1 or 1.5 spectra per second, so mass spectra needed to be established much faster. A so-called time of flight (TOF) detector is able to handle narrow peaks from GCxGC up to 500 spectra per second. This increases the number of detected components tremendously.

The naturalness of an essential oil can also be investigated by ^{13}C NMR (nuclear magnetic resonance). This method is based on the detection of the magnetic properties of ^{13}C nuclei. Separation of the oil is unnecessary. It is an expensive method but provides very accurate results (19).

For most of the applications described in this section, standards on the technique of testing have been created by ISO (International Organization for Standardization, www.iso.org) (20). More information on the analysis of essential oils can be found in ref. 17.

2.10 QUALITY, PURITY AND ADULTERATION OF ESSENTIAL OILS

Essential oils sold on the internet often bear labels as 'pure', 'natural', or '100% natural'. Such labelling does not guarantee that the oils are of good quality. In fact, such labelling should not be necessary as, according to ISO standards (11), essential oils must be natural and pure. Indeed, good-quality oils on the market conform to the standards laid down by ISO for individual essential oils. However, it cannot be denied that lesser-quality products are commercially available. Poor or lesser quality of essential oils can have various causes, including adulteration, contamination, inadequate oil production and aging (Table 2.5).

Table 2.5 Causes of lesser quality of essential oils

Adulteration
Addition of foreign substances

- Fat oils, ethanol, water (formerly)
- Other essential oils (turpentine oil to pine needle of fir oil; cananga oil to ylang-ylang oil)
- Fractions of essential oils (including foreruns) and defined natural isolates
- Steam-distilled citrus oil added to expressed (genuine) citrus oils
- Synthetic chemicals known to occur in nature: linalool, menthol, limonene

Prohibited non-physical methods for rectifying oils
Intentional mixing of biomass before distillation (cananga blossoms with ylang-ylang, formerly lavandin flowers with lavender)

Contamination
Chemicals from packing material
Chemical residues from inadequately cleansed distillation stills
Chemical residues from inadequately cleansed drums and other containers

Inadequate production
Use of wrong species
Use of more than one species or subspecies
Use of several chemotypes of one species

Aging
Formation of allergenic oxidation products (tea tree oil, citrus oils, lavender oil, turpentine oil)

Adulteration

Adulteration may be described as making essential oils impure or inferior by adding foreign substances. The methods and materials for adulteration are manifold. Often terms as cutting, stretching or bouqetting are used as euphemisms. Adulteration can have many reasons, but the main reason is to make more profit. Demands of clients of the essential oil industry are another reason. For some parties, lower prices are more important than genuineness and quality of the oils. Sometimes, adulteration is performed to ensure sufficient supply of oils to clients, e.g., in the case of a bad harvest, rapidly rising demand from the market or speculation with oil, and to avoid large variations in market prices.

Materials used for adulteration

Formerly, *fat oils*, *ethanol* and even *water* were used for adulteration. The presence of ethanol can be an adulteration, but it may also be a normal ingredient of certain essential oils. Rose oils, for example, may have up to 7% of ethanol according to its ISO standard (23). In other oils, ethanol concentrations of <0.1% are accepted. While water used to be an adulterant, it is currently considered doubtful whether its presence indicates adulteration. Many essential oils are able to bind a certain amount of water. In the production of citrus oils, large quantities of water are used. Although the oil is separated by centrifugation, some water will remain in the oils. Conifer oils such as pine and fir oil can also contain some water. The water-binding capacity of oils increases with higher temperatures and, thus, especially oils produced in the summer may contain appreciable amounts of water. To check this, a larger sample is placed in a measuring glass cylinder in the refrigerator for some days, after which the water is visualized at the bottom and its content can be quantified.

Adulteration by adding other essential oils is common. Turpentine oil, for example, is used to stretch pine needle or fir needle oil. The main components of all three oils are α- and β-pinene, and as turpentine oil is far cheaper than the others, this is a perfect blending material. Cananga oil may be added to the – far more expensive – ylang-ylang oil.

Fractions of essential oils and *defined natural isolates* are also useful for adulteration, notably for cutting other, more expensive ones. Many essential oils undergo fractional distillation for flavor purposes and these fractions are used to 'lift up' the concentration of chemicals in other essential oils to the desired or maximum allowed concentration. Although they are from natural sources, the mingling with oils from other plant species prohibits the oil from being termed essential oil. Limonene is such a component, which is available in high purity at a moderate price. Another is citral, which is distilled from litsea cubeba oil and can be added to lemon oil. However, it has a different ratio of geranial to neral and is, compared to synthetic citral, much more expensive. Geraniol can be distilled in high purity from palmarosa oil or citronella Sri Lanka oil and may be added to the more expensive geranium or rose oils. Eugenol can easily be distilled from clove leaf oil, the cheapest clove oil, and is used to increase its concentration in clove bud or pimento berry oil. Linalool from ho leaf oil (ex *Cinnamomum camphora*) is sometimes added to lavender, clary sage or rosewood oil. So-called foreruns, multicomponent mixtures (monoterpenes like tricyclene, limonene, pinenes, camphene, etc.) can also be used to adulterate other oils.

The peels of citrus fruits still contain some essential oil after cold-pressing. Therefore, these peels are often hydrodistilled and the *hydrodistilled citrus oils* thus produced (which are – with the exception of lime oil – not essential oils) are often added to the genuine, cold-pressed citrus essential oils.

Finally, adulteration may be performed by adding chemically produced *synthetic compounds*, which are known to be present in nature. They are often termed 'nature identical' compounds, but this term may not be used anymore in Europe in the context of flavors and fragrances. They are not recovered from plants, but from other sources, usually from petroleum fractions. However, in the production process, usually by-products are generated, which can easily be detected by GC-MS. The finding of dehydro- and dihydrolinalool and -linalyl acetate, for example, indicates adulteration with synthetic linalool/linalyl acetate. In addition, synthetic linalool and linalyl acetate are racemic mixtures ((*S*)- and (*R*)-), whereas in nature only the 3*R*-(-)- enantiomers are found.

Sometimes, oils from the same species, but coming from different geographic areas, are mixed. This is *not* considered adulteration. Lemon oils originating from Italy, Spain, USA and Argentina can be mixed and are still lemon essential oils. However, the origin of the oil is sometimes specifically mentioned, as it has increased value, exclusivity or its name is protected, e.g., in the case of Italian lemon oil. However, when Italian lemon oil is mixed with lemon oil from Argentina, it cannot be sold anymore as lemon oil Italian.

Sometimes essential oils have to be post-treated (rectified) to diminish the concentration of one or more chemicals or remove it/them completely, when they are considered dangerous (phototoxicity, carcinogenic properties). For some chemicals, allowed concentrations are regulated by IFRA (International Fragrance Association) or by governmental laws, e.g., European Union legislation. In bergamot oil, for example, the phototoxic psoralens are reduced or eliminated, by using either physical or chemical methods. The chemical methods are not allowed according ISO rules and to avoid the loss of naturalness, users did not agree to such a treatment.

A last form of what might be considered adulteration is intentional mixing of biomass from two species before distillation. Cananga blossoms, for example, may be added to ylang-ylang flowers, as they have a higher content of oil. In former times, lavandin blossoms were added to lavender blossoms to increase the (desired) linalyl content.

All forms of adulteration can be detected by analytical techniques (17,18).

Contamination

Contamination is the presence of low concentrations of foreign chemicals in essential oils, which have entered the product unintentionally. Phthalates such as ethyl phthalate may be contaminants from their presence as softeners in plastic packing material or containers. Storage of essential oil in drums that previously contained other chemicals and that have not been cleaned properly will lead to quality loss. Improper cleaning of the distillation unit may also cause problems. A well-known example is melissa oil produced in a plant that had previously been used for thyme oil distillation. The melissa oil was contaminated with thymol and could not be commercialized anymore.

Inadequate production

Most essential oils must be produced from one species. When cultivated plants are used, this demand can easily be fulfilled. However, sometimes biomass is collected from plants growing in the wild. This bears the risk, especially in the case of producers that have insufficient knowledge and experience, that the oil will be prepared from not only the intended species, but also from other, similar-looking, plant (sub)species. In addition, several chemotypes of identical-looking plants may be mixed, which means that the concentration of the major ingredients will most likely not conform to the ISO standard. Examples are oils produced from *Thymus* and *Cinnamomum* species.

Especially in developing countries, production plants are not always equipped to control parameters that guarantee optimal distillation. Perfect biomass which is distilled incorrectly, e.g., too much steam, too high temperatures, or a badly functioning cooling unit, will inevitably lead to lower-quality oils.

Aging

When essential oils are stored under the wrong conditions (too warm, exposure to light and oxygen), a chemical process occurs called aging. As a result of esterification, reduction and oxidization of chemicals, the composition of the oil changes. In aged lemon oil, for example, the concentrations of limonene, γ-terpinene and citral are reduced and the amounts of *p*-cymene, *cis*-8,9-limonene oxide and 2,3-epoxygeraniol increase (22). In fact, the concentration of *p*-cymene in lemon oil can be considered a marker for the aging process. The main problem with this form of aging is that peroxides and hydroperoxides are formed, which may be strong allergens. It is well known, for example, that important essential oil ingredients such as linalool, limonene, geraniol and citronellol are weak contact allergens, but that their auto-oxidation products have far stronger sensitizing capacities (7,8,9,43). Such oxidation products are well-known causes of contact allergy to tea tree oil (Chapter 5.83) and turpentine oil (Chapter 5.87).

LITERATURE

1. Lawrence BM. A preliminary report on the world production of some selected essential oils and countries. Perfum Flavor 2009;34(1):38-44
2. Lawrence BM. A planning scheme to evaluate new aromatic plants for the flavor and fragrance industries. In: J Janick and JE Simon, Eds. New crops. New York: Wiley, 1993:620-627
3. Schmidt E, Wanner J, Höferl M, Jirovetz L, Buchbauer G, Gochec V, et al. Chemical composition, olfactory analysis and antibacterial activity of *Thymus vulgaris* L. chemo-types geraniol, thujanol-4/terpinen-4-ol, thymol and linalool cultivated in Southern France. Nat Prod Commun 2012;7:1095-1098
4. Levey M. Evidence of ancient distillation in Mesopotamia. Centaurus 1959;4(1):23-33
5. Gildemeister E, Hoffmann F. Die Ätherische Öle. Leipzig, Germany: Verlag Schimmel & Co, 1931
6. Schmidt E. Production of essential oils. In: HC Baser and G Buchbauer, Eds. Handbook of essential oils: Science, technology and applications. Boca Raton, London, New York: CRC Press, Taylor & Francis Group, 2010:83-119
7. Rudbäck J, Hagvall L, Börje A, Nilsson U, Karlberg A-T. Characterization of skin sensitizers from autoxidized citronellol – impact of the terpene structure on the autoxidation process. Contact Dermatitis 2014;70:329-339
8. Hagvall L, Backtorp C, Svensson S, Nyman G, Börje A, Karlberg AT. Fragrance compound geraniol forms contact allergens on air exposure. Identification and quantification of oxidation products and effect on skin sensitization. Chem Res Toxicol 2007;20: 807-814
9. Nilsson U, Bergh M, Shao LP, Karlberg A-T. Analysis of contact allergenic compounds in oxidized d-limonene. Chromatographia 1996;42:199-205
10. Franz C, Baser KHC, Windisch W. Essential oils and aromatic plants in animal feeding – a European perspective. A review. Flavour Fragr J 2010;25:327-340
11. ISO 9235:2013 Aromatic natural raw materials – Vocabulary. International Organization for Standardization, Geneva, Switzerland. www.iso.org
12. Müller MP, Lamparsky D. Perfumes: Art, science, and technology. London, New York: Elsevier Science Publishers Ltd, 1991:348-362
13. Franz C. Genetics. In: RKM Hay and PG Waterman, Eds. Volatile oil crops: Their biology, biochemistry and production. Harlow, UK: Longman Scientific & Technical, 1993:63-96
14. Erdtmann H. Some aspects of chemotaxonomy. In: T Swain, Ed. Chemical plant taxonomy, 2nd Ed. New York: Academic Press, 1963:89-125
15. Kaloustian J. Southern French thyme oils: chromatographic study of chemo-types. J Sci Food Agric 2005;85:2437-2444
16. Desjardins AE. Natural product chemistry meets genetics: When is a genotype a chemotype? J Agric Food Chem 2008;56:7587-7592
17. Schmidt E, Wanner J. Adulteration of essential oils. In: HC Baser and G Buchbauer, Eds. Handbook of essential oils: Science, technology and applications, 2nd Edition. Boca Raton, London: CRC Press, Taylor & Francis Group, 2015
18. Busch KW, Busch MA. Chiral analysis. Amsterdam: Elsevier, 2006:47-48
19. Kubezka KH, Formácek V. Essential oil analysis by capillary gas chromatography and carbon-13 NMR spectroscopy. Chichester, UK: John Wiley & Sons, 2002

20 http://www.iso.org/iso/home/search.htm?qt=Essential+oils&published=on&active

21 Gerbers K. Buch über die Chemie des Parfüms und seine Destillationen. Ein Beitrag zur Geschichte der Arabischen Parfümchemie und Drogenkunde aus dem 9. Jahrhundert P.C. Leipzig, Germany: Kommissionsverlag F.A. Brockhaus, 1948. Translated from KITAB KIMIYA' AL-'ITR WAT-TAS'IDAT

22 Dugo G, Cotroneo A, Bonaccorsi I, Trozzi A. Composition of the volatile fraction of citrus peel oils. In: G Dugo and L Mondello, Eds. Citrus oils. Composition, advanced analytical techniques, contaminants, and biological activity. Boca Raton, Fl., USA: CRC Press, Taylor & Francis Group, 2011:147

23 ISO/DIS 9842:2003 Oil of rose (*Rosa* x *damascena* Miller), International Organization for Standardization, Geneva, Switzerland, www.iso.org

24 Dugo G, Mondello L, Eds. Citrus Oils. Composition, advanced analytical techniques, contaminants, and biological activity. Boca Raton, Fl., USA: CRC Press, Taylor & Francis Group, 2011

25 Rhind JP. Essential oils. A handbook for aromatherapy practice, 2nd Edition. London: Singing Dragon, 2012

26 Lawless J. The encyclopedia of essential oils, 2nd Edition. London: Harper Thorsons, 2014

27 Davis P. Aromatherapy. An A-Z, 3rd Edition. London: Vermilion, 2005

28 ISO 22716:2007 Cosmetics – Good Manufacturing Practices (GMP) – Guidelines on Good Manufacturing Practices. International Organization for Standardization, Geneva, Switzerland, www.iso.org

29 Nardelli A, Thijs L, Janssen K, Goossens A. Rosa centifolia in a 'non-scented' moisturizing body lotion as a cause of allergic contact dermatitis. Contact Dermatitis 2009;61:306-309

30 Tisserand R, Young R. Essential oil safety, 2nd Edition. Edinburgh, UK: Churchill Livingstone Elsevier, 2014

31 Schmidt E. Unpublished observations

32 Becker PM, Galetti S. Food and feed components for gut health-promoting adhesion of *E. coli* and *Salmonella enterica*. J Sci Food Agric 2008;88:2026-2035

33 Ehrlinger M. Phytogene Zusatzstoffe in der Tierernährung. Inaugural-Dissertation, Tierärztliche Fakultät der Ludwig-Maximilians-Universität, München, Germany, 2007:235-247

34 Breitmaier E. Terpenes: Flavors, fragrances, pharmaca, pheromones. Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA, 2008:10-85

35 Surburg H, Panten J. Common fragrance and flavor materials, 5th Edition. Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA, 2006:8-162

36 Terpenoids. Cyperlipid Center. http://www.cyberlipid.org/simple/simp0004.htm

37 Rowe DJ. Chemistry and technology of flavors and fragrances. Oxford, UK: Blackwell Publishing Ltd, 2005:56-131

38 Sherma J. Thin-layer chromatography in food and agricultural analysis. J. Chromatogr A 2000;880:129-147

39 d'Acampora Zellner B, Dugo P, Dugo G, Mondello L. Analysis of essential oils. In: HC Baser and G Buchbauer, Eds. Handbook of essential oils: Science, technology and applications. Boca Raton, London, New York: CRC Press, Taylor & Francis Group, 2010:151-184

40 NIST/EPA/NIH Mass Spectral Library. Wiley. www.wiley.com

41 Adams RP. Identification of essential oil components by gas chromatography/mass spectrometry, 4th Edition. Carol Stream, IL, USA: Allured Publishing Corporation, 2007

42 Massfinder 4. Hamburg, Germany: Dr. Hochmuth Scientific Consulting, 2014. http://massfinder.com/wiki/MassFinder_4

43 Karlberg A-T, Börje A, Johansen JD, Lidén C, Rastogi S, Roberts D, et al. Activation of non-sensitizing or low-sensitizing fragrance substances into potent sensitizers – prehaptens and prohaptens. Contact Dermatitis 2013;69:323-334

Chapter 3 CONTACT ALLERGY TO ESSENTIAL OILS: GENERAL ASPECTS

In this chapter, general aspects of contact allergy to essential oils are discussed. Literature data on specific aspects of contact allergy to and allergic contact dermatitis from individual oils are presented in Chapters 5.1-5.93.

3.1 ESSENTIAL OILS WHICH HAVE CAUSED CONTACT ALLERGY

In our literature search, we have found 79 essential oils (essential oils as per ISO definitions) which have caused contact allergy (positive patch test reactions) or allergic contact dermatitis. They are shown in Table 3.1; the numbers in the first column refer to chapter numbers of the individual oils. The number of Chapters (n=93) exceeds the number of oils which have caused contact allergy, which is explained as follows. Some essential oils can be obtained from more than one part of a source plant: cassia oil from the bark or from the leaves of *Cinnamomum cassia*; the same goes for cinnamon oil. Clove oil is usually obtained from the leaves of the plant *Syzygium aromaticum* L., but can also have buds or even the stem as source biomass. In other cases, essential oils with the same commonly used name can be obtained from different plant *species*. Thus, cedarwood oil may be produced from five plant species resulting in cedarwood oil Atlas, cedarwood oil China, cedarwood oil Himalaya, cedarwood oil Texas and cedarwood oil Virginia. Eucalyptus oil can be obtained from *Corymbia citriodora* or from *Eucalyptus globulus*. The same situation applies to lemongrass oil (*Cymbopogon flexuosus* yields East Indian lemongrass oil, whereas West Indian lemongrass oil is produced from *Cymbopogon citratus*), sage oil (Dalmatian sage oil from *Salvia officinalis*, Spanish sage oil from *Salvia lavandulifolia*) and thyme oil can be produced from *Thymus vulgaris* (thyme oil) or from *Thymus zygis* (Spanish thyme oil). Jasmine absolutes can be produced from *Jasminum grandiflorum* or from *Jasminum sambac*. Lavandin oils, finally, are all obtained by steam-distilling the flowering tops of the lavandin (bastard lavender), *Lavandula angustifolia* Mill. x *Lavandula latifolia* Medik., but from different cultivars such as 'Abrial', 'Grosso' and 'Super'. In literature on contact allergy to essential oils, the exact nature of the oil (plant species, plant part used) is rarely mentioned and oils are termed cassia oil, cedarwood oil, cinnamon oil, clove oil, eucalyptus oil etc. However, the composition of these oils, which are presented under the same name, can differ considerably and depends on the source species and the plant parts used. For some, there are specific ISO standards, e.g., lavandin 'Abrial', lavandin 'Grosso', clove bud, clove leaf, clove stem, both eucalyptus oils, two jasmine absolutes, both lemongrass oils, both sage oils and an ISO file for Spanish thyme oil. Therefore, we have decided to include full chapters on the chemical composition of these oils, although they have not been reported to cause contact allergy *under their specific names*.

Of the 79 oils that have caused allergic contact dermatitis or contact allergy, 45 have been tested in groups of consecutive patients suspected of contact dermatitis. Testing in groups of *selected* patients has been performed with 53 essential oils, usually in patients suspected of fragrance allergy, of cosmetic dermatitis, or patients who previously had a positive reaction to the fragrance mix or one of the other indicators of fragrance allergy such as *Myroxylon pereirae* resin (balsam of Peru). Case reports of allergic contact dermatitis were found for 67 oils. For 37 essential oils, data on positive patch test reactions that had no relevance, or the relevance of which was uncertain or not mentioned, are provided; these are usually reactions to oils tested in a fragrance series. General aspects of routine testing data and case reports are discussed below. Specific data on all aspects of contact allergy / allergic contact dermatitis can be found in the individual oil files in Chapters 5.1-5.93.

3.2 FREQUENCY OF CONTACT ALLERGY TO ESSENTIALS OILS

For the frequency of contact allergy to essential oils, prevalence rates of positive patch test reactions, tested in consecutive patients suspected of contact dermatitis, can be used as an indication. Relevant data are summarized in Table 3.2. Forty-five essential oils have been tested in consecutive patients; the number of studies per oil ranges from 1 to 19. For 21 oils of this group (47%), information is limited to one study; in the case of 15 of these 21 oils, this was a study from Poland published in 1976, in which a very small group of 200 dermatitis patients was tested with 35 essential oils (2).

For 17 oils, the highest prevalence rate observed was 1.0% or lower. Eleven oils have had maximum rates of positive patch test reactions between 1% and 1.5% and in only nine have rates over 2% been observed. These are, in order of descending maximum values, laurel oil 6.9% (observed between 1953 and 1962 in a period with many reactions in Germany, France and Switzerland from its presence in ointments, which most likely was *vegetable* laurel *berries* oil; data cited in ref. 3), turpentine oil 4.2% (study from Spain from before 1986; in Germany in 1998 a 4.4% prevalence was observed, thereafter declining to 1.5-2%), orange oil 3.2% (study from 1967 to 1970), tea tree oil 2.7%, citronella oil 2.5% (very small 1976 study), ylang-ylang oil 2.6%, sandalwood oil 2.4%, clove oil 2.1% (observed in a weak study with a high rate of macular erythema and weak reactions) and costus root oil 2.1% (small study from 1982, historical allergen). These are the highest prevalence rates observed for these oils; in other studies (far) lower percentages have been found. Thus, it appears that contact allergy to essential oils as a group is not frequent (although in the general German adult population, 2.5% of 1141 test subjects reacted to oil of turpentine, 4.3% of the women and 0.7% of the men) (133). Currently the highest prevalences of positive

Table 3.1 Essential oils which have cause contact allergy/allergic contact dermatitis

Chapter	Name of essential oil	Number of publications found in literature				
		Routine testing[a]	Selective testing[b]	Case reports[c]	Positive patch tests[d]	Probable allergen(s) identified[e]
5.1	Angelica oil (unspecified)	1	1	1		
5.1	Angelica fruit oil			1		α-pinene
5.2	Angelica root oil		1	1		
5.3	Aniseed oil		1	4	1	anethole
5.4	Basil oil, sweet			2		linalool
5.5	Bay oil		1			eugenol
5.6	Bergamot oil	5	2	4	1	limonene, linalool, β-pinene
5.7	Black cumin oil			6		
5.8	Black pepper oil			1		caryophyllene, α-pinene
5.9	Cajeput oil			1		caryophyllene, α-pinene
5.10	Calamus oil		2			
5.11	Cananga oil	3	12	2	8	
5.92	Cardamom oil			1		
5.12	Carrot seed oil			1		
5.13	Cassia oil (unspecified)	2	2	5	1	cinnamic aldehyde
5.13	Cassia bark oil					
5.14	Cassia leaf oil					
5.15	Cedarwood oil (unspecified)	3	3	3		
5.15	Cedarwood oil, Atlas	2				
5.16	Cedarwood oil, China	2				
5.93	Cedarwood oil, Himalaya	1	1			
5.17	Cedarwood oil, Texas					
5.18	Cedarwood oil, Virginia		1			
5.19	Chamomile oil (unspecified)	2	2	2		α-pinene
5.19	Chamomile oil, German		3			
5.20	Chamomile oil, Roman		1	2		
5.21	Cinnamon oil (unspecified)		1	13	3	cinnamic aldehyde, eugenol
5.21	Cinnamon bark oil, Sri Lanka					
5.22	Cinnamon leaf oil, Sri Lanka	1	1		1	eugenol
5.23	Citronella oil (unspecified)[f]	1	2	4	1	citronellal, citronellol, geraniol, geranyl acetate, limonene
5.23	Citronella oil, Java				1	limonene
5.24	Citronella oil, Sri Lanka			1		limonene
5.25	Clary sage oil	1	2	4	1	geraniol, linalool
5.26	Clove oil (unspecified)[f]	3	8	8	3	eugenol
5.26	Clove bud oil		2			
5.27	Clove leaf oil					
5.28	Clove stem oil					
5.29	Coriander fruit oil	1	2	1	1	linalool, α-pinene
5.30	Costus root oil	1		2	2	
5.31	Cypress oil			3		α-pinene
5.32	Dwarf pine oil	2	1	1	2	
5.33	Elemi oil			1		
5.34	Eucalyptus oil (unspecified)	2	7	7	1	α-pinene
5.34	Eucalyptus citriodora oil					
5.35	Eucalyptus globulus oil			1		
5.36	Galbanum resin oil			1		α-pinene
5.37	Geranium oil	1	12	14	3	caryophyllene, citral (neral + geranial), citronellol, geraniol, linalool
5.38	Ginger oil			1		
5.39	Grapefruit oil			1		
5.40	Guaiacwood oil		2			
5.41	Hyssop oil			1		
5.42	Jasmine absolute (unspecified) + Jasminum grandiflorum abs.	12	13	5	8	eugenol, linalool
5.43	Jasminum sambac absolute					

Table 3.1 Essential oils which have cause contact allergy/allergic contact dermatitis (*continued*)

		Number of publications found in literature				
Chapter	Name of essential oil	Routine testing[a]	Selective testing[b]	Case reports[c]	Positive patch tests[d]	Probable allergen(s) identified[e]
5.44	Juniper berry oil[f]	1	2	1		α-pinene
5.45	Laurel leaf oil[f, g]	1	5	7	4	
5.46	Lavandin abrial oil					
5.47	Lavandin grosso oil					
5.48	Lavandin oil (unspecified)	1	2	1		
5.49	Lavender oil	3	5	19	8	caryophyllene, linalool
5.50	Lemon oil	2	7	9	4	limonene, β-pinene
5.51	Lemongrass oil (unspecified) + Lemongrass oil, East Indian	4	5	8	5	citral (geranial + neral), geraniol
5.52	Lemongrass oil, West Indian					
5.53	Litsea cubeba oil	1	2			
5.54	Lovage oil			2		
5.55	Mandarin oil			1		
5.56	Marjoram oil (sweet)			2		caryophyllene, linalool, α-pinene
5.57	Melissa oil (lemon balm oil)			2		caryophyllene, geraniol
5.58	Myrrh oil			2	1	
5.59	Neem oil			3		
5.60	Neroli oil	1	4	9	4	geraniol
5.61	Niaouli oil[f]			3		α-pinene
5.62	Nutmeg oil				1	
5.63	Olibanum (frankincense) oil			2	1	caryophyllene, α-pinene
5.64	Orange oil (unspecified)[f]	2	3	4	1	
5.64	Orange oil, bitter	1	2			
5.65	Orange oil, sweet[f]	1	2	2	1	limonene
5.66	Palmarosa oil				2	
5.67	Patchouli oil	3	5		3	
5.68	Peppermint oil[f]	10	11	18	9	caryophyllene, limonene, menthol, α-pinene, piperitone, pulegone
5.69	Petitgrain bigarade oil	1	2	2		geraniol, linalool
5.70	Pine needle oil	2	3	4	2	α-pinene
5.71	Ravensara oil			2		linalool, α-pinene
5.72	Rosemary oil		1	2	1	linalool, α-pinene
5.73	Rose oil	1	7	8	8	citronellol, geraniol, linalool
5.74	Rosewood oil			2		linalool
5.75	Sage oil (unspecified)			1		
5.75	Sage oil, Dalmatian					
5.76	Sage oil, Spanish					
5.77	Sandalwood oil[f]	8	17	4	3	santalol
5.78	Silver fir oil	1	2			
5.79	Spearmint oil	3	8	11		carvone
5.80	Spike lavender oil	1	2			
5.81	Star anise oil	1				anethole, methyl chavicol, limonene
5.82	Tangerine oil			1		
5.83	Tea tree oil	19	5	30	NR	aromadendrene, ascaridole, *d*-carvone, *l*-carvone, 1,8-cineole, *p*-cymene, *d*-limonene, myrcene, α-phellandrene, α-terpinene, terpinen-4-ol, terpino-lene, 1,2,4-trihydroxymenthane, sabinene and viridiflorene
5.84	Thuja oil			1		
5.85	Thyme oil (unspecified)[f]		3			
5.85	Thyme oil				1	linalool, α-pinene
5.86	Thyme oil, Spanish					
5.87	Turpentine oil	13	8	12	2	dipentene, α-phellandrene, α-pinene, β-pinene, α-terpineol
5.88	Valerian oil				1	

Table 3.1 Essential oils which have cause contact allergy/allergic contact dermatitis (*continued*)

		Number of publications found in literature				
Chapter	Name of essential oil	Routine testing[a]	Selective testing[b]	Case reports[c]	Positive patch tests[d]	Probable allergen(s) identified[e]
5.89	Vetiver oil	1	2	2		
5.90	Ylang-ylang oil	14	15	10	11	caryophyllene, linalool
5.91	Zdravetz oil	1	2			
5.92	see Cardamom oil					
5.93	see Cedarwood oil, Himalaya					

[a] testing in consecutive patients suspected of contact dermatitis

[b] testing in groups of selected patients, e.g., patients suspected of fragrance allergy, patients with previous positive patch tests to the fragrance mix or *Myroxylon pereirae* resin (balsam of Peru)

[c] cases of allergic contact dermatitis with extensive or limited clinical description or positive patch tests indicated by the authors as relevant for the patient's dermatitis

[d] positive patch tests, the relevance of which was unknown, uncertain or not stated

[e] patch test reactivity of one or more chemicals which have been demonstrated in the essential oil used by the patient by chemical analysis, or known to be present in such oils in high concentrations (e.g., geraniol in geranium and rose oils, citronellal and citronellol in citronella oils, cinnamaldehyde in cinnamon oils), or which have been demonstrated in commercial samples of the essential oil in question in concentrations >3% (analytical data from Erich Schmidt, shown in the oil chapters 5.1-5.93, usually in column A of Table 2)

[f] additional references are given for these oils; their data are not included in this table

[g] laurel oil in older publications was not the essential oil from laurel leaves, but mostly fatty oil expressed from laurel berries

NR not recorded: data on positive patch test reactions with no, unknown or uncertain relevance have not been collected because of the abundance of other literature on tea tree oil

Table 3.2 Prevalence rates of sensitization to essential oils in routine testing and relevance data

Name of essential oil	Nr. of studies	Nr. of patients (total)	Time frame of studies/publications	Prevalence range	Relevance data (% relevant)
Angelica oil (unspecified)	1	200	1976	1.0%	NS
Bergamot oil	5	2,490	1977-2007	0.2-1.5%	NS; 100%[a]
Cananga oil	3	1,108	1976-2007	0.5-1.2%	NS; 100%[a]
Cassia oil (unspecified)	2	950	1976-1985	0.7-1.0%	NS
Cedarwood oil (unspecified)	3	2,124	1976-2000	0.6-1.5%	NS
Cedarwood oil, Himalaya	1	200	1976	1.5%	NS
Chamomile oil (unspecified)	2	490	1967-1976	0.3-0.5%	NS
Cinnamon leaf oil	1	1,382	1975	1.1%	NS
Citronella oil (unspecified)	1	200	1976	2.5%	NS
Clary sage oil	1	200	1976	0.5%	NS
Clove oil (unspecified)	3	906	1967-2007	0.3-2.1%	NS; 100%[a]
Coriander fruit oil	1	200	1976	1.0%	NS
Costus root oil	1	282	1982	2.1%	NS
Dwarf pine oil	2	1,606	1998-2000	0.6-0.7%	NS
Eucalyptus oil (unspecified)	2	879	1976-2007	0.6-1.5%	NS; 100%[a]
Geranium oil	1	486	2000-2007	1.2%	100%[a]
Jasmine absolute (unspecified)[b] + Jasminum grandiflorum abs.	12	32,708	1983-2012	0.3-1.5%	NS; 9-37%[c]; 92%[a]
Juniper berry oil	1	200	1976	0.5%	NS
Laurel leaf oil	1	>1,000	1953-1962	3.1-6.9%[d]	NS
Lavandin oil (unspecified)	1	200	1976	0.5%	NS
Lavender oil[b]	3	8,953	2002-2012	0.1-1.2%	NS; 30-69%[c]
Lemon oil	2	545	1976-2003	0.5-0.9%	NS; 100%[a]

Table 3.2 Prevalence rates of sensitization to essential oils in routine testing and relevance data (*continued*)

Name of essential oil	Nr. of studies	Nr. of patients (total)	Time frame of studies/publications	Prevalence range	Relevance data (% relevant)
Lemongrass oil (unspecified) + Lemongrass oil, East Indian	4	4,909	1998-2008	0.6-1.6%	NS; 100%[a]
Litsea cubeba oil	1	200	1976	1.5%	NS
Neroli oil	1	324	2000-2007	0.3%	100%[a]
Orange oil (unspecified)	2	1,268	1967-2007	0.6-3.2%	NS[e]
Orange oil, bitter	1	200	1976	1.5%	NS
Orange oil, sweet	1	200	1976	0.5%	NS
Patchouli oil	3	4,052	1998-2008	0.6-0.9%	NS
Peppermint oil[b]	10	14,326	1970-2012	0.3-1.8%	NS; 36-39%[c]; 100%[a]
Petitgrain bigarade oil	1	200	1976	0.5%	NS
Pine needle oil	2	3,700	1973-1976	0.4-2.0%	NS
Rose oil	1	679	2000-2007	1.6%	100%[a]
Sandalwood oil	8	10,921	1983-2008	0.1-2.4%	NS; 82%[a]
Silver fir oil	1	200	1976	1.0%	NS
Spearmint oil	3	2,106	1998-2007	0.8-1.6%	NS; 100%[a]
Spike lavender oil	1	200	1976	0.5%	NS
Tea tree oil[b]	19	44,964	1997-2013	0.1-2.7%	NS; average 40%
Turpentine oil	13	253,065	1972-2008	1.2-4.2%	NS
Vetiver oil	1	200	1976	0.5%	NS
Ylang-ylang oil[b]	14	37,356	1976-2012	0.7-2.6%	NS; 0-27%[c]; 100%[a]
Zdravetz oil	1	200	1976	0.5%	NS

[a] rather weak study; relevance data included 'questionable' and 'past' relevance (132)

[b] currently present in the North American Contact Dermatitis Group (NACDG) screening series

[c] definite + probable relevance in the NACDG studies

[d] very old data from Germany, when laurel oil caused many reactions from its presence in ointments; however, it was most likely *vegetable* oil from laurel *berries* (data cited in ref. 3)

[e] in an Italian study with a 3.2% prevalence rate of sensitization, many patients had contact with oranges

NS: not specified, not stated or unknown

patch test reactions are observed – depending on the country to tea tree oil, ylang-ylang oil and sandalwood oil (which for sandalwood oil is rather curious, because its price is so high that it is virtually only used in fine fragrances), but these cannot – on the basis of current data – be regarded as frequent and important sensitizers. In the past, however, ylang-ylang oil, jasmine absolute, cananga oil and some other essential oils have caused many cases of allergic reactions to cosmetics in Japan (see below in the section 'Pigmented cosmetic dermatitis').

3.3 CLINICAL RELEVANCE OF POSITIVE PATCH TEST REACTIONS TO ESSENTIAL OILS

The finding of a positive patch test reaction to an essential oil should – as with any test substance – be followed by determination of its relevance: can the dermatitis of the patient be (partly) explained by contact with the oil or products containing it? As all dermatologists know, this is the most difficult part of the diagnostic procedure. This unfortunately is evident from relevance data of the studies shown in Table 3.2. In >80% of all studies, no information on relevance was provided. In nearly 2/3 of all oils, no information on relevance is available at all. In one study, the observed patch test reactions to the tested essential oils were considered to be relevant in 82-100%. Unfortunately, this was a rather weak study, where questionable and past relevance were included (132). The NACDG provides relevance data for the essential oils which are included in the NACDG screening series. Current relevance is defined as definite (use test with the suspected item was positive, or a patch test to the object or product was positive), probable (the antigen could be verified as present in known skin contactants and clinical presentation was consistent), or possible (patient was exposed to circumstances in which skin contact with materials known to contain the allergen was likely to occur (4). Percentages for definite + probable relevance were as follows: lavender oil 30-69%, tea tree oil 20-56%, peppermint oil 36-39%, jasmine absolute 14-37% and ylang-ylang oil 0-27%. Rates for definite relevance were usually <10-15% and sometimes zero. It may thus be concluded that reliable data on the relevance of positive patch test reactions to essential oils as reported in literature are largely lacking or inadequate. Insufficient knowledge of the chemical composition of essential oils and difficulties in ascertaining whether oils or their ingredients are present in materials with which the patients have contact may partly be responsible. It should be realized that previously acquired contact allergy to a fragrance chemical per se may result in a (non-relevant) positive patch test to an essential oil containing it, e.g., when tested in the fragrance series. For example, a patient sensitized to geraniol in a cream showed positive reactions to Bulgarian rose oil and geranium oil Bourbon, to which the patient had apparently not been exposed, but both of which contain high concentrations of geraniol, likely explaining the positive patch test reactions (131).

Of 14 patients with occupational contact dermatitis from *d*-limonene and patch tested with tea tree oil 5% in petrolatum, 5 (36%) had a positive (n=4) or doubtful positive (n=1) reaction to tea tree oil. This indicates that previously acquired contact allergy to limonene may result in a non-relevant positive patch test to tea tree oil (134). In fact, we think it is likely that many positive patch test reactions to essential oils in routine testing, for which no relevance can be ascertained, may well be explained this way and that sensitization is not the result of contact with the essential oil itself.

3.4 REPORTS OF ALLERGIC CONTACT DERMATITIS FROM ESSENTIAL OILS

Case reports of allergic contact dermatitis have been described for 67 essential oils; the numbers per oil range from 1 (21 oils) to >10: spearmint oil 11, turpentine oil 12, cinnamon oil 13, geranium oil 14, peppermint oil 18, lavender oil 19, tea tree oil 30. These include both cases with proper clinical data and some cases where positive patch tests were considered by the authors to be relevant (testing in groups of patients excluded). It should, however, be realized that some patients with allergic contact dermatitis have reacted to a large number of essential oils with which they had contact and that these particular case reports are shown in all of these oils. Of two aromatherapists with occupational allergic contact dermatitis, for example, one reacted to 32 and the other to 21 essential oils (5).

3.5 CLINICAL PICTURE OF ALLERGIC CONTACT DERMATITIS FROM ESSENTIAL OILS

There are no descriptions of the clinical picture of allergic contact dermatitis from essential oils in larger groups of patients. As the products in which the oils may be present vary considerably (pure oils, perfumes, toothpastes, other cosmetics, topical pharmaceutical preparations, other products: see the section ‘Products responsible for allergic contact dermatitis to essential oils’ below), as do the sites of application and the goals of applying the oils to the skin, the presentation of patients with allergic contact dermatitis may take many forms. These are sometimes easy, in other cases difficult to recognize as essential oil related.

There have been many case reports of patients who developed occupational allergic contact dermatitis from oils used for massaging clients, including aromatherapists, masseuses, and physiotherapists. The patients are usually women and present with dermatitis of the hands and sometimes of the forearms; in a number of them, dermatitis spreads to other parts of the body and may become generalized (96) (see the section ‘Occupational allergic contact dermatitis’ below). In clients receiving the massages, generalized allergic contact dermatitis may develop (81).

Undiluted oils are also frequently applied for therapeutic purposes, notably tea tree oil. Dermatitis will appear at the site of application and may stay limited to the primary site, but spreading of dermatitis is not infrequent and even generalization occurs occasionally (13,80). Unilateral dermatitis of the cheeks may be caused by lavender drops applied on the pillow for their presumed hypnotic effects (19).

Many topical pharmaceutical products contain essential oils, usually as fragrance rather than as an active ingredient. Allergic contact dermatitis from such products will develop at the site of application. In a large group of 127 patients with iatrogenic allergic contact dermatitis from essential oils (and other fragrances) in topical pharmaceutical drugs, women were more affected than men, and legs, hands, and face were the most commonly affected body sites (59). The use of vaginal suppositories has led to erythematous vulvitis, leucorrhoea and patches of dermatitis on the buttocks (66).

Allergic reactions of the oral mucosa and lips

Essential oils are frequently added to toothpastes, especially spearmint, peppermint and cinnamon oils. Contact allergy may lead to symptoms of the oral mucosa, the lips and the perioral skin. Possible oral manifestations include burning/ sore mouth (40,53), stomatitis (40,43,50,51,58), swelling of the tongue, lips and gingival mucosa (40) and ulceration of the mouth (40,44). There are some indications that oral lichen planus may be worsened by contact allergy to essential oils (48,74,75). Oral symptoms can also be caused by contact allergy to other products for oral use such as antiseptic spray, mouthwash (47,52) and chewing gum (52). The lips often show cheilitis (allergic contact dermatitis of the lips) (40,42,43,49,50,51), which may be erosive (54); fissuring can sometime be observed (53) as is angular cheilitis (44). The allergic reaction may also result in dermatitis of the surrounding skin (40,44,53). Rarely, dermatitis of the fingers or the palm has been described from toothpaste running along the toothbrush on the hand (43,46); cheilitis or stomatitis may even be absent then (46). Of course, cheilitis can also be caused by products applied to the lips, such as lip balms (34). Recurrence of cinnamon oil-induced cheilitis by eating cinnamon has been observed (82).

Pigmented cosmetic dermatitis

In Japan, in the 1960s and 1970s, many female Japanese patients developed facial pigmentation following dermatitis of the face (6). This so-called pigmented cosmetic dermatitis was shown to be caused by contact allergy to components of cosmetic products, notably essential oils (ylang-ylang, cananga, lavender, sandalwood), jasmine absolute, other fragrance materials, antimicrobials, preservatives and coloring materials (6,9). The number of patients decreased strongly after

1978, when major cosmetic companies began to eliminate strong contact sensitizers from their products, including dihydro-isoeugenol from ylang-ylang oil (7,8,9). Pigmented contact dermatitis from essential oil allergy is still seen occasionally (39,80).

Other forms of dermatitis

Airborne allergic contact dermatitis has been observed from inhaling the vapors of a hot aqueous solution of tea tree oil (83) and the spreading of essential oils in the air through aromatherapy lamps (84). Systemic administration of tea tree oil has worsened dermatitis from topical application (systemic contact dermatitis) (125).

Sometimes allergic contact dermatitis from essential oils may present itself as erythema multiforme-like reactions (14,76). In two cases, topical application and ingestion of black cumin oil resulted in generalized erythema multiforme and bullous erythema multiforme / toxic epidermal necrolysis (77,78). In one patient, contact allergy to tea tree oil applied undiluted to a piercing wound may have precipitated linear IgA disease (79).

3.6 PRODUCTS RESPONSIBLE FOR ALLERGIC CONTACT DERMATITIS FROM ESSENTIAL OILS

Various categories of products responsible for allergic contact dermatitis from essential oils can be distinguished:

Pure oils

Case reports of allergic contact dermatitis from contact with pure oils have been reported repeatedly, e.g., from patchouli oil (10), black cumin oil (11,13), citronella oil (12), laurel oil (14,16), neem oil (17), lovage oil (18), and – through indirect contact by application on a pillow – lavender oil (19). These reactions can be expected especially with oils that have alleged therapeutic actions when applied to the skin. This is certainly the case with tea tree oils, which are used topically for therapeutic purposes on a variety of skin conditions including acne, eczema, sunburn, wounds (of any cause), warts, herpes and fungal infections. At least 85 patients with allergic contact dermatitis from tea tree oil have been described in case reports. Of the cases where the products responsible for the allergic reactions were specified, most (63%) related to pure tea tree oil (for references see Chapter 5.83). A separate category of patients who become sensitized to pure oils or diluted oils in high concentrations is that of people who have frequent contact with such products at work, e.g., aromatherapists and masseurs. Many such cases of occupational contact dermatitis to essential oils have been described (see the section 'Occupational contact dermatitis' below).

Cosmetic products

Essential oils are widely used in cosmetic products and the development of allergic cosmetic dermatitis from them has been reported in a number of publications. However, related to their widespread use, the role of cosmetics in essential oil contact allergy is modest. Examples are shown in Table 3.3.

Toothpastes and other oral preparations

Although toothpastes are diluted under normal use circumstances and the contact time with the oral mucosa, lips, and perioral skin is short, essential oils in these products have been reported to cause contact allergic reactions repeatedly: cinnamon oil (40,42,43,44,45,46), spearmint oil (51,53,54,56,57), peppermint oil (49,50,51), cassia oil (40,42,43), aniseed oil (58) and laurel oil (35). Oil of cassia and oil of cloves have caused contact allergy in a dental tablet (41), peppermint oil in antiseptic spray (47), in mint-flavored mouthwashes and foods (48) and spearmint oil in mouth rinses and chewing gum (52).

Table 3.3 Reported cases of contact allergy to essential oils in cosmetic products

Essential oil	Cosmetic products and number of patients[b]	References
Angelica root oil	Eye cream	29
Black cumin oil	Skin care product	30
Citronella oil	Deodorant	31
Eucalyptus oil	Bath/shower product, skin care product	21
Geranium oil	Aftershave, hair dye, face cream, nail polish, lip balm	26,34
Jasmine absolute	Face cream	26
Laurel oil	Face mask	35
Lavender oil	Bath/shower product (2), skin care product, deodorant, massage product, shampoo, perfume, gel	21,36,37,38
Lemon oil	Face powder	39
Neroli oil	Skin care product, facial moisturizer	21,28
Niaouli oil	Skin care product	21
Orange oil	Skin care product	21
Peppermint oil	Depilatory product, lip balm	23,27
Rose oil	Perfume (2), face cream, skin care product (3), hand soap ('fragrance-free'), body lotion[a]	21,25,26,34, 119
Tea tree oil	Shaving gel, shampoo (2), skin care product (6), soap and cream, cream, shaving oil	20,21,22,23,
Ylang-ylang oil	Eye cream	29

[a] *Rosa centifolia* oil; [b] the number of patients is one for each product category per oil unless indicated otherwise

Pharmaceutical products

In the period 1978-2008, allergic contact dermatitis from essential oils present in topical pharmaceutical products was diagnosed in Leuven, Belgium as follows: lavender oil (n=24), neroli oil (n=14), geranium oil (n=12), eucalyptus oil (n=10), rose oil (n=5), pine needle oil (n=4), laurel oil (n=2) and tea tree oil (n=2) (59). There may be overlap with the two cases of contact allergy to pine needle oil, five to neroli oil, and two to eucalyptus oil documented in another Belgian study (60). Other case reports of essential oil allergy from its presence in topical pharmaceutical preparations include: tea tree oil in wart paint (61); peppermint oil in a transdermal therapeutic system (62); two cases of neroli oil in a topical NSAID preparation (63, may also overlap with refs. 59 and 60); two cases of Roman chamomile oil in Kamillosan® (64) and one in a homeopathic preparation (65); cinnamon oil in a vaginal suppository (66); dwarf pine oil in a topical NSAID preparation (67); eucalyptus oil in Vicks Vaporub (68) and in an anti-inflammatory cream (69); geranium oil in a topical preparation to promote wound healing and prevent scar formation (70) and two cases of lavender oil allergy from their presence in antihistamine creams (71,72).

Other products

Other products in which essential oils have caused allergic contact dermatitis have included immersion oil for dermatoscopy (the essential oil was a contaminant) (85), cedarwood oil used as the vehicle for applying a black henna temporary tattoo (86), cinnamon oil added to a mud bath in a spa (87), aromatherapy lamps (whereby the water vapour produced distributes the essential oils as an aerosol in the air (84) and wax polish (88).

3.7 OCCUPATIONAL ALLERGIC CONTACT DERMATITIS FROM ESSENTIAL OILS

Massage professionals

Occupational allergic contact dermatitis from essential oils has been reported repeatedly in professionals who massage their clients. Frequent contact, contact with highly concentrated essential oil products and the use of multiple oils, often containing the same allergens, all contribute to the risk of sensitization. The potential relationship of hand dermatitis with the use of aromatherapy products among massage therapists has been investigated (89). The 12-month rate of hand dermatitis was 15% by self-reported criteria and 23% by symptom-based criteria. A significant independent risk factor was the use of products such as massage oils, creams or lotions containing essential oils (89). A study from Germany showed that massage therapists and physiotherapists had the highest occupational risk of fragrance contact allergy (90). Patients are usually female and present with hand dermatitis, which may spread to the forearms and other parts of the body. When patch-tested, they usually react to a (large) number of essential oils used at work, oils tested in a fragrance series and individual fragrances therein; in 70% of the cases, there is co-reactivity to the fragrance mix I and often also to the fragrance mix II and *Myroxylon pereirae* resin (balsam of Peru) (see the section 'Co-reactivity to other test substances in patients reacting to essential oils' below). Occupational allergic contact dermatitis in professionals performing massages has been observed in aromatherapists (5,94,95,96,97,100), beauticians/beauty therapists (20,91,92,99), complementary therapists (20,28), masseurs (73,93), a naturopathic therapist (73), physiotherapists (73,98) and a reflexologist (73).

Workers in the fragrance and cosmetic industries

Lovage oil sensitized one worker in the fragrance industry (104). Six bottle fillers in a perfume factory became sensitized to the perfumes they worked with, various fragrance materials and essential oils (101). A patient working in a cosmetic factory had occupational dermatitis from contact allergy to ylang-ylang oil in a fragrance mixture he was handling daily (105). A woman packing cosmetics developed occupational allergic contact dermatitis from ylang-ylang oil (106). Bergamot oil sensitized one worker in the fragrance industry (111).

Clary sage oil caused dermatitis in an unknown number of perfumery workers (114).

Workers in the food industries

Occupational hand dermatitis from lemon oil was diagnosed in a cook/barman/fruit grower (102). One case of occupational contact allergy to spearmint oil in a chewing gum finisher has been reported (107). Occupational allergic contact dermatitis from eucalyptus oil (ex *E. globulus*) was observed in one patient with hand dermatitis working in the food industry; an unknown number of food handlers were sensitized to peppermint oil (108). Two patients working in the food industry developed occupational allergic contact dermatitis from aniseed oil and its main ingredient anethole (109). One patient had cheilitis from contact allergy to the vapour of cinnamon oil to which she was occupationally exposed while making bubble gum (112). Hand dermatitis in a baker was ascribed to cinnamon oil (113).

Other occupations

A porter became sensitized to oil of lemon, which he used occupationally (12). Eight of 30 men working on a boat developed dermatitis which was caused by accidental contact with lemongrass oil which had been spilled (103).

A hairdresser who had occupational contact dermatitis of the hands developed contact allergy to lavender oil which was present in a shampoo used at work (36). Another hairdresser developed occupational contact allergy to lavender oil from its presence in an eau de cologne (37). A pedicurist developed dermatitis of the left side of the face from tea tree oil she used to stop small point bleedings in her patients (92). One patient working as painter and car mechanic developed occupational contact dermatitis from pine oil in a wax polish (88). One case of occupational allergic contact dermatitis in a porcelain painter due to anise, turpentine and lavender oils, which were mixed with pigments for painting, was reported (110). Oil from juniper berries was an occupational allergen for the skin and respiratory tract (115, specifics unknown).

3.8 CO-REACTIVITY TO OTHER TEST SUBSTANCES IN PATIENTS REACTING TO ESSENTIAL OILS

In most publications, patients reacting positively to an essential oil co-reacted – if tested – to other essential oils, the fragrance mix I, the fragrance mix II, *Myroxylon pereirae* resin (balsam of Peru), individual fragrance chemicals, or a combination of these. There are (at least) three possible explanations. In many such cases, co-reactivity probably results from pseudo-cross-reactivity, meaning that the test substances share common components responsible for the positive patch test reactions. In a number of cases, real cross-reactivity may play a role. Third, as many patients (e.g., in the case of occupational contact allergy) are exposed to a large number of essential oils and possibly individual fragrances, concomitant sensitization to various products and chemicals can be anticipated.

Co-reactivity to other essential oils

Many patients in case reports react to a great number of essential oils, which is certainly true for aromatherapists and other professionals using oils and essential oil-containing products for massaging their clients (28,96,97,100).

Of two aromatherapists, for example, one reacted to 32 and the other to 21 essential oils (5). Another aromatherapist was patch test positive to 17 of 20 oils used at her work (95). In a group of 19 patients allergic to fragrances and tested with a series of essential oils, 6 reacted to one oil only, 3 to two oils, 3 to three, 3 to four, 1 to five, 1 reacted to seven oils and 1 even had positive patch test reactions to nine oils (116).

Co-reactivity between cananga oil and ylang-ylang oil

Of eight patients with dermatitis from fragrances and reacting to ylang-ylang oil, seven (88%) also reacted to cananga oil (116). Conversely, of seven patients with dermatitis from fragrances and reacting to cananga oil, all co-reacted to ylang-ylang oil (116). Simultaneous reactivity has also been observed in many case reports. Both oils are obtained from the tree *Cananga odorata*, ylang-ylang oil from its *forma genuina* and cananga oil from its *forma macryphylla* and they have similarities in their compositions.

Co-reactions to the fragrance mixes

Co-reactivity to the fragrance mix I (FM I) (and to a lesser degree to the fragrance mix II (FM II), which was introduced more recently) in patients with contact allergy to or allergic contact dermatitis from essential oils is very frequent, both in case reports (e.g., 5,28,73,95,96,97,100,119) and in investigations in groups of patients. Of 637 patients reacting to at least one essential oil seen by the IVDK (Germany, Austria, Switzerland), 55% co-reacted to FM I, 35% to FM II and 63% to one of these two (117). Of 15 patients reacting to ylang-ylang oil in The Netherlands, 15 (83%) co-reacted to FM I (120). Co-reactivity to FM for individual essential oils as observed in a European multi-center study was as follows: ylang-ylang oil 36/42 (86%), lemongrass oil 18/25 (72%), jasmine absolute 11/20 (55%) and patchouli oil 9/13 (69%) (121). Co-reactivity to FM I in individuals with positive patch tests to turpentine oil (which is nearly exclusively tested by the IVDK) was 46% (122).

Co-reactions to *Myroxylon pereirae* resin and colophony

Of 431 patients reacting to turpentine oil, *Myroxylon pereirae* resin co-reacted in 29% (versus 7% in turpentine-negative patients) and colophony in 23% (versus 3% in turpentine-negative patients), which makes these associations statistically significant (122). Positive reactions to colophony (which is the material that remains after hydrodistillation of gum resin of *Pinus* species to produce turpentine oils) are associated especially with essential oils of woody origin such as dwarf pine needle oil, sandalwood oil and cedarwood oil (123). A statistically significant association between positive patch test reactions to essential oils and the Compositae-mix has also been reported (123).

Co-reactivity to important components of essential oils (individual fragrance chemicals)

This is discussed below in the section ‘The allergens in essential oils’.

3.9 ANALYTICAL INVESTIGATION OF THE COMPONENTS OF ESSENTIAL OILS WHICH HAVE CAUSED ALLERGIC CONTACT DERMATITIS

In few published investigations, analyses of essential oils used by patients allergic to them have been performed. This is especially useful when patients also react to individual fragrance chemicals; the analysis can show the presence (or absence) of such chemicals in the oils. Quantitative analysis can determine the concentration of the chemicals and thus give an indication of whether the positive patch test reaction to the oils can be caused by these components.

In the most extensive analytical investigation performed thus far, one sample of 27 essential oils each and two samples of 11 other essential oils each, used by one or two aromatherapists, who reacted to many of these oils, were investigated by GC-MS (5). One of the patients was also allergic to geraniol, linalool, linalyl acetate and α-pinene, the other to geraniol, α-pinene and caryophyllene. α-Pinene was demonstrated in 42 oil samples, of which 13 had concentrations of 1-10% (v/v) and 5 of >10%. Linalool was found in 22 samples, of which 9 had concentrations of 1-10% (v/v) and 11 of >10%. Geraniol was present in 16 oil samples, of which 7 had concentrations of 1-10% (v/v) and 8 of >10%. Linalool was found in 22 samples, of which 9 had concentrations of 1-10% (v/v) and 11 of >10%. Caryophyllene was identified in 37 samples, of which 20 had concentrations of 1-10% (v/v) and 9 of >10% (5).

Bergamot oil sensitized one female worker in the fragrance industry, who also reacted to α-pinene and β-pinene. Commercial bergamot oils were investigated for the presence of these chemicals and they were identified in maximum concentrations of 1.7% (α-pinene) and 9.3% (β-pinene) (111).

One patient suspected to be allergic to incense had positive patch tests to two brands of incense, sandalwood oil, musk ambrette and santalol; gas chromatography of pentane:ether extracts of the incense showed 9% and 34% musk ambrette and 8% santalol in both incenses; the sandalwood oil extract had 73% santalol, which is the dominant component of sandalwood oil (124).

One patient developed contact allergy to a perfume; she reacted to the fragrance mix, Bulgarian rose oil and geraniol; chromatographic analysis of the perfume showed it to contain 33% citronellol and 20% geraniol (126).

One patient became sensitized from the topical application of pure tea tree oil for therapeutic purposes (125). Gas chromatography/mass spectrometry identified a number of components, including 1,8-cineole. The patient was tested with 1,8 cineole and retested with tea tree oil and reacted to both test substances. The concentration of this chemical was not determined (125). For analytical investigations of tea tree oil samples see Chapter 5.83.

3.10 THE ALLERGENS IN ESSENTIAL OILS

With the exception of tea tree oil and turpentine oil, large-scale patch testing with components of essential oils in allergic patients in order to determine the major sensitizers has not been performed. Tea tree oil, stored in open bottles or in a bottle opened several times, suffers an aging process resulting in photo-oxidation leading to degradation products (peroxides, epoxides and endoperoxides), which are strong sensitizers. The most important sensitizers in tea tree oil appear to be terpinolene, ascaridole, α-terpinene and its oxidation products, 1,2,4-trihydroxymenthane, α-phellandrene, *d*-limonene and myrcene. Other chemicals which may be responsible for tea tree oil allergy, albeit less frequently, include aromadendrene, *d*-carvone, *l*-carvone, terpinen-4-ol, viridiflorene, sabinene, *p*-cymene and 1,8-cineole. Most of these have been found in low concentrations or not at all in commercial tea tree oils, which can be explained by the fact that these were fresh oil samples (see Chapter 5.83). In turpentine oil, the allergens are δ3-carene hydroperoxides (in oils from Scandinavia [probably hardly used anymore] and Indonesia), α-pinene, oxidized limonene, β-pinene, α-terpineol, and rarely α-phellandrene (see Chapter 5.87). In Poland, 30% of patients allergic to turpentine oil also reacted to pine needle oil; α-pinene is the major ingredient (and important allergen) of turpentine oil and also an important component of pine needle oil, with concentrations in commercial oils ranging from 13 to 20% (133).

For some other oils, their major allergens can tentatively be identified on the basis of their general composition and co-reactions to important ingredients in patch testing as documented in literature. For example, 50% of 94 patients allergic to clove (bud) oil co-reacted to eugenol, which is the major ingredient (>82%) of this essential oil (117). Of 13 patients known to be allergic to *Myroxylon pereirae*, propolis and clove oil, 6 (46%) reacted to eugenol, which is a component of all three test substances (128). Eugenol is also an important component of bay oil (40-55%). Of seven patients reacting to bay oil and tested with eugenol, five (71%) co-reacted to eugenol (116).

In the case of lemongrass oil, of 67 patients reacting to this oil, 34 (51%) also reacted to citral; citral consists of geranial + neral, both of which are the dominant ingredients of lemongrass oils (117). Commercial geranium oils contain 6-32% geraniol. Co-reactivity to geraniol in patients reacting to geranium oil has been observed in at least 50% of those tested with geraniol (129,131,132). Geraniol sensitivity is also observed in patients reacting to rose oils (131,132); commercial rose oils contain 5-24% geraniol. In cinnamon oil, cinnamaldehyde is the major component (43-73%) and this chemical has co-reacted repeatedly in patients allergic to cinnamon oils (Chapter 5.21). Menthol (23-48% in commercial oils) is probably the most important sensitizer in peppermint oils (Chapter 5.68). Spearmint oils contain 60-80% carvone. In about 50% of the patients allergic to spearmint oil in who carvone is tested, co-reactivity occurs (Chapter 5.79). In citrus peel oils (bergamot, grapefruit, lemon, orange, mandarin, tangerine), limonene is by far the most important constituent, but has thus far not been identified as the main allergen. The reason may be that patients allergic to citrus peel oils have not yet been tested with oxidized limonene, which is the allergenic form of limonene (127). Probably for the same reason, linalool has as yet not been found as a major allergenic ingredient of lavender and ylang-ylang oils, in which high concentrations of linalool and linalyl acetate are present.

Possible or probable allergens in essential oils are shown in Table 3.1 (right column); for specific data see Chapters 5.1-5.93.

3.11 PATCH TESTING WITH ESSENTIAL OILS AND THEIR INGREDIENTS

Essential oils should be patch tested in any patient suspected of contact allergy to these oils on the basis of the history and the clinical picture. Suspicion is high in cases of hand dermatitis in aromatherapists, masseuses etc., in patients working in the fragrance industry, the food industry and in individuals who have applied essential oils to their skin, e.g., for therapeutic purposes (notably tea tree oil). In addition, in any patient with symptoms of the oral mucosa, lips (cheilitis) and the perioral skin, contact allergy to essential oils in toothpastes or other oral preparations should be considered. However, the range of products in which essential oils can be present is broad and localization and aspect of essential oil-induced allergic contact dermatitis are often not specific.

Several essential oils are available as commercial patch test substances (Table 3.4) In the USA four essential oils and one absolute (tea tree oil 5%, lavender oil 2%, peppermint oil 2%, jasmine absolute 2% and ylang-ylang

Table 3.4 Essential oils, fragrance components and other chemicals identified in essential oils which are commercially available for patch testing

Patch test allergen	Suppliers			
	Trolab	**Chemo**	**Brial**	**Allergeaze**
ESSENTIAL OILS				
Bergamot oil			2%	2%
Cananga oil		2%^{f}		
Cedarwood oil	10%		10%^{k}	10%^{k}
Cinnamon oil			0.5%^{l}	0.5%^{l}
Clove oil	2%		2%^{m}	2%^{m}
Eucalyptus oil	2%		2%^{n}	
Geranium oil, Bourbon		2%^{g}		
Jasmine absolute	5%	2%^{e}	2%^{o}	2%^{b,o}
Laurel leaf oil	2%		2%	2%
Lavender oil		2%^{h}	2%	2%
Lemongrass oil	2%		2%^{p}	2%^{p}
Lemon oil	2%		2%	2%
Neroli oil	2%		5%	2 and 5%
Orange oil	2%		2%	2%
Patchouli oil	10%			10%
Peppermint oil	2%	2%	2%	2%
Rosemary oil			0.5%	0.5%
Rose oil		2%, *extract*	0.5%^{q}	0.5%^{q}
Sandalwood oil	10%	2%^{c,d}		10%^{r}
Tea tree oil		5% ox.		5% ox.
Turpentine oil	10%	0.4% ox.^{i}	10%^{r}	10%^{s}
Ylang-ylang oil	10%	2%^{j}		2%
FRAGRANCES / OTHER CHEMICALS IDENTIFIED IN ESSENTIAL OILS				
Fragrances				
Amyl cinnamal (α-amylcinnamic aldehyde)	1%	2%	1%	1%
α-Amylcinnamic alcohol	1%	5%	1%	1%
Anethole		5%		
Anisyl alcohol	1%	10% Soft.	1%	1%
Benzaldehyde	5%		5%	5%
Benzoic acid		5%	5%	1 and 5%
Benzyl alcohol	1%	10% Soft.	1 and 5%	1 and 5%
Benzyl benzoate	1%	10%	1%	1%
Benzyl cinnamate	5%	10%	5%	5%
Benzyl salicylate	1%	10%	1%	1%
Camphor			1%	1%
Carvone		5%		5%
Cinnamal (cinnamic aldehyde)	1%	1%	1%	1%
Cinnamyl alcohol	1%	2%	1%	1%
Citral	2%	2%	2%	2%
Citronellal			2%	2%
Citronellol	1%	1%	1%	1%
Coumarin	5%	5%	5%	5%
Dipentene (*dl*-limonene)	2%			
Eugenol	1%	2%	1%	1%
Farnesol	5%	5%	5%	5%
Geraniol	1%	2%	1%	1%
Hexyl cinnamal (α-hexylcinnamic aldehyde)	10%	10%	10%	10%
Hydroxycitronellal^{t}	1%	2%	1%	1%
Isoeugenol	1%	2%	1%	1%
α-Isomethyl ionone (γ-methylionone)^{a,t}	1%	10%		0.1%
d-Limonene		10%	2%	2 and 3%
Limonene hydroperoxides		0.3%		0.3%
Linalool	10%	10%		
Linalool hydroperoxides		1%		1%
Menthol	1%	2%	1%	1%
Methyl anthranilate		5%		
Methyl salicylate			2%	2%
α-Pinene			15%	15%
Salicylaldehyde	2%		2%	2%

Table 3.4 Essential oils, fragrance components and other chemicals identified in essential oils which are commercially available for patch testing (*continued*)

Patch test allergen	Suppliers			
	Trolab	**Chemo**	**Brial**	**Allergeaze**
Thymol			1%	1%
Vanillin	10%	10%	10%	10%
Chemicals identified in essential oils, so far not found in nature				
Butylphenyl methylpropional (Lilial®, *p-tert*-butyl-α-methyl-hydrocinnamic aldehyde)	10%	10%		
Dibutyl phthalate	5%	5%	5%	5%
Di-(2-ethylhexyl) phthalate (dioctyl phthalate)	5%	5%	5%	5%
Diethyl phthalate			5%	5%
Dimethyl phthalate	5%		5%	5%
Hydroxycitronellal	1%	2%	1%	1%
Hydroxyisohexyl 3-cyclohexene carboxaldehyde (Lyral®)	5%	5%	5%	5%
α-Isomethyl ionone (γ-methylionone)[a]	1%	10%		0.1%
Musk ambrette			5%	5%
Indicators of fragrance / essential oils allergy				
Colophonium (rosin)	20%	20%	20%	20%
Compositae mix		2.5 and 5%	6%	6%
Fragrance mix I (cinnamyl alcohol, cinnamal, hydroxycitronellal, amyl cinnamal, geraniol, eugenol, isoeugenol, *Evernia prunastri*)	8%	8%	8%	8%
Fragrance mix II (citral, citronellol, coumarin, farnesol, hexyl cinnamal, hydroxyisohexyl 3-cyclohexene carboxaldehyde [Lyral®])	14%	14%	14%	14%
Myroxylon pereirae (Balsam of Peru)	25%	25%	25%	25%
Perfume mix (cinnamyl alcohol, cinnamal, hydroxycitronellal, eugenol, Isoeugenol, geraniol)		6%		
Sesquiterpene lactone mix (alantolactone, costunolide, dehydrocostus lactone)	0.1%	0.1%	0.1%	0.1%

Trolab: www.smartpracticeurope.com.de; Chemotechnique: www.chemotechnique.se; Brial: www.brial.com; Allergeaze: www.allergeaze.com

All test substances are in petrolatum unless otherwise indicated

ox.: oxidized; Soft.: Softisan

[a] the chemical which was found in essential oils is 'methylionone'

[b] 'jasmine oil officinale (grandiflorum)'

[c] produced from *Santalum album*: main ingredients are β-santalol 21% and α-santalol 50% (information from Chemotechnique)

[d] in some patients, 2% may be too low to detect sensitization (121)

[e] jasmine absolute *ex J. grandiflorum;* main ingredients are benzyl benzoate 10-20%, phytol 10-20%, isophytol 5-10%, linalool 5-10%, eugenol 5-10%, benzyl alcohol 1-5% and benzyl salicylate 0.1-1% (information from Chemotechnique)

[f] main ingredients: β-caryophyllene 30-40%, geranyl acetate 5-10%, benzyl benzoate 1-5%, linalool 1-5%, methyl benzoate 1-5%, benzyl salicylate 1-5%, farnesol 1-5%, *p*-cresyl methyl ether 1-5%, geraniol 1-5% (information from Chemotechnique)

[g] main ingredients: DL-citronellol 30-40%, geraniol 10-20%, linalool 10-20%, menthone 5-10% and citral 1-5% (information from Chemotechnique)

[h] main ingredients are linalool 20-30%, linalyl acetate 20-30%, coumarin 10-20%, terpinen-4-ol 1-5%, geraniol 0.1-1% and caryophyllene oxide 0.1-1% (information from Chemotechnique); the test substance is prepared from lavender *absolute*

[i] main ingredients are δ3-carene 40-65% and α-pinene <20% (information from Chemotechnique); obtained from *Pinus roxburghii* Sarg.

[j] main ingredients are 'other hydrocarbons' 30-40%, linalool 10-20%, *p*-cresyl methyl ether 10-20%, β-caryophyllene 5-10%, geranyl acetate 5-10%, methyl benzoate 5-10%, benzyl benzoate 5-10%, benzyl salicylate 1-5%, farnesol 1-5%, geraniol 1-5% and isoeugenol 1-5% (information from Chemotechnique)

[k] prepared from Virginian cedarwood oil (information from Brial/Allergeaze)

[l] cinnamon bark oil from *Cinnamomum zeylanicum* (information from Brial/Allergeaze)

[m] clove bud oil (information from Brial/Allergeaze)

[n] eucalyptus oil ex *E. globulus* (information from Brial)

[o] prepared from *Jasminum sambac* (information from Brial/Allergeaze)

[p] West Indian lemongrass oil produced from *Cymbopogon citratus* (information from Brial/Allergeaze)

[q] *synthetic* rose oil (information from Brial/Allergeaze)

[r] prepared from *Pinus pinaster* (information from Brial/Allergeaze)

[s] prepared from *Santalum album* (information from Brial/Allergeaze)

[t] has not been found in nature so far

Table 3.5 Suggested patch test concentrations for chemicals for which there are no commercial test preparations

Chemical	CAS number	Patch test concentration(s) and vehicles
Acetyl cedrene	32388-55-9	1 and 5% pet.; 10% DIPP
Ambrettolide	7779-50-2	5% pet.
Aromadendrene	489-39-4	1% alc.; 5% DEP
Ascaridole	512-85-6	2% pet.; 5% DEP or aq.
Azulene	275-51-4	1% pet.
Benzyl acetate	140-11-4	1 and 5% pet.
Benzyl propionate	122-63-4	3% pet.
Bisabolol	515-69-5	5% pet.
δ3-Carene	13466-78-9	5% pet.; 15% o.o.
Carvacrol	499-75-2	5% pet.
β-Caryophyllene	87-44-5	5% pet.; 3% pet., ox.
Caryophyllene oxide	1139-30-6	3.9% pet.
1,8-Cineole	470-82-6	5% pet., DEP or alc.
Cinnamic acid	621-82-9	5% pet.
Cinnamyl cinnamate	122-69-0	5% pet.
Coniferyl alcohol	458-35-5	1% pet.
Coniferyl benzoate	4159-29-9	1% pet.
Cuminaldehyde	122-03-2	10% pet.
p-Cymene	99-87-6	1% alc.; 5% DEP
β-Damascone	23726-91-2	0.2% pet.
Dihydrocoumarin	119-84-6	5% pet.
Falcarinol	21852-80-2	0.03-2% pet.
Geranial	141-27-5	1.5-3.5% pet.
Geranyl acetate	105-87-3	3% pet.
Guaiazulene	489-84-9	1% pet.
Heptanal	111-71-7	3% pet.
Hexadecanolide	109-29-5	5% pet.
(*Z*)-3-Hexenyl salicylate	65405-77-8	3% pet.
Hydroxycitronellol	107-74-4	7% pet.
α-Ionone	127-41-3	5-10% pet.
β-Ionone	79-77-6	5-10% pet.
Isoeugenyl acetate	93-29-8	1.2% alc.
Isopulegol	89-79-2	5% pet.
Isosafrole	120-58-1	5% pet.
Isothymol	4427-56-9	2% pet.
Limonene oxide	1195-92-2	1% pet.
Linalyl acetate	115-95-7	5-10% pet.
o-Methoxycinnamaldehyde (2)	1504-74-1	4% pet.
7-Methoxycoumarin	531-59-9	1% pet.
8-Methoxypsoralen	298-81-7	0.15% pet.
Methyl *p*-anisate	121-98-2	4% pet.
Methyl cinnamate	103-26-4	10% pet.
Methyl dihydrojas-monate	24851-98-7	1 and 5% pet.
Methyl eugenol	93-15-2	5% pet.
Methyl isoeugenol	93-16-3	5% pet.
Myrcene	123-35-3	1 and 5% o.o.; 5% pet.; 3% pet., ox.
Neral	106-26-3	1.5-3.5% pet.
Nerol	106-25-2	5% pet.
Nerolidol	7212-44-4	1% pet.
Nonanal	124-19-6	1% pet.
Nonanol	28473-21-4	2% pet.
Nopyl acetate	128-51-8	10% pet.
Octanol	29063-28-3	2% pet.
α-Phellandrene	99-83-2	1% alc.; 5% DEP or aq.
2-Phenethyl alcohol	60-12-8	1-10% pet.
Phenylacetaldehyde	122-78-1	2% pet.
β-Pinene	127-91-3	1% pet.; 15% o.o.
Piperitone	89-81-6	10% pet.
Piperonal	120-57-0	1 and 5% pet.
Propylidene phthalide	17369-59-4	2% pet.
Pulegone	89-82-7	10% pet.
Sabinene	3387-41-5	5% DEP
Safrole	94-59-7	1% pet.
Santalol		2-10% pet.

Table 3.5 Suggested patch test concentrations for chemicals for which there are no commercial test preparations (*continued*)

Chemical	CAS number	Patch test concentration(s) and vehicles
α-Terpinene	99-86-5	1% alc.; 5% DEP or aq.
Terpinen-4-ol	562-74-3	1 and 5% alc. or DEP; 10% alc., DEP or aq.
α-Terpineol	98-55-5	1 and 5% pet.; 1 and 10% alc.
Terpinolene	586-62-9	1% alc.; 5% pet.; 10% DEP or aq.
Terpinyl acetate	8007-35-0	5% pet.
1,2,4-Trihydroxymenthane		5% DEP or pet.
Viridiflorene	21747-46-6	5% DEP

alc.: alcohol; aq.: aqua, water; DEP: diethyl phthalate; DIPP: diisopropylene glycol; o.o.: olive oil; ox.: oxidized; pet.: petrolatum

oil 2%) are currently present in the screening series of the North American Contact Dermatitis Group (NACDG) and tested in all consecutive patients suspected of contact dermatitis (1). Many other investigators test a series of essential oils and other fragrance materials (available commercial test substances are shown in Table 3.4) only when fragrance contact allergy is suspected; another indication for further testing is when a patient has previously shown positive patch test reactions to one or more of the fragrance indicator allergens, such as the fragrance mix(es) and *Myroxylon pereirae* resin, to other fragrance materials, or to the patient's personal fragrances or fragranced cosmetics. For screening purposes, these series of commercial allergens are very useful. However, when patients have a history of contact with one or more oils, it is preferable (if not imperative) to test these products themselves, because of the strong variability that may occur in the composition of essential oils. In addition, in aged oils that have been exposed to light, oxygen and temperature changes, new allergenic chemicals may have formed (which is well known in, for example, tea tree oil and lavender oil) which are not present in adequately stored (cool, dark, unexposed to air) commercial test substances.

For most essential oils, testing at 2-5% in petrolatum (or both, unless many oils are tested, risk of great number of reactions with false-positives due to the excited skin syndrome) will likely be adequate. Lower concentrations may be appropriate for costus root oil (0.1%, very unlikely to encounter, historical allergen), black cumin oil (0.5%), star anise oil (0.5%, it may be preferable to test the main ingredient anethole 5%), and cassia and cinnamon (bark) oils (1%, because of the very high concentrations of cinnamic aldehyde). The various cedarwood oils may be tested as follows: cedarwood oil Atlas 8%, cedarwood oil China 10%, cedarwood oil Virginia 8%; for silver fir oil, 10% may be appropriate. When obtaining positive patch tests to one or more essential oils, a search for the allergenic ingredients should preferably be initiated. Likely candidates are discussed above in the section 'The allergens in essential oils' and in Table 3.1, right column. It is advisable to consult the individual oil chapters (Chapters 5.1-5.93) to identify important components. A list of all chemicals which can be present in essential oils and which have caused contact allergy (usually not from their presence in essential oils) is provided in Chapter 4. The chemicals from this list which are commercially available are shown in Table 3.4. Suggested patch test concentrations for chemicals in this list which cannot be purchased as commercial test preparations are shown in Table 3.5.

LITERATURE

1 Cheng J, Zug KA. Fragrance allergic contact dermatitis. Dermatitis 2014;25:232-245
2 Rudzki E, Grzywa Z, Bruo WS. Sensitivity to 35 essential oils. Contact Dermatitis 1976;2:196-200
3 Foussereau J, Benezra C, Ourisson G. Contact dermatitis from laurel. I. Clinical aspects. Transactions of the St John's Hospital Dermatological Society 1967;53:141-146
4 Warshaw EM, Maibach HI, Taylor JS, Sasseville D, DeKoven JG, Zirwas MJ, et al. North American Contact Dermatitis Group patch test results: 2011-2012. Dermatitis 2015;26:49-59
5 Dharmagunawardena B, Takwale A, Sanders KJ, Cannan S, Roger A, Ilchyshyn A. Gas chromatography: an investigative tool in multiple allergies to essential oils. Contact Dermatitis 2002;47:288-292
6 Nakayama H, Harada R, Toda M. Pigmented cosmetic dermatitis. Int J Dermatol 1976;15:673-675
7 Sugawara M, Nakayama H, Watanabe S. Contact hypersensitivity to ylang-ylang oil. Contact Dermatitis 1990;23:248-249
8 Toyoda T, Watanabe S, Kawasaki M, et al. Dihydroisoeugenol found in ylang-ylang oil. Skin Res 1989;31 (suppl.7):35-43 (in Japanese)
9 Nakayama H, Matsuo S, Hayakawa K, Takhashi K, Shigematsu T, Ota S. Pigmented cosmetic dermatitis. Int J Dermatol 1984;23:299-305
10 Hausen BM, Kunze B. Kontaktallergie auf Patchouli-Öl. Akt Dermatol 1991;17:199-202
11 Steinmann A, Schätzle M, Agathos M, Breit R. Allergic contact dermatitis from black cumin (*Nigella sativa*) oil after topical use. Contact Dermatitis 1997;36:268-269
12 Keil H. Contact dermatitis due to oil of citronellal. J Invest Dermatol 1947;8:327-334

13 Lleonart R, Andrés B, Molinero J, Corominas M. Systemic allergic contact dermatitis due to black cumin oil. Contact Dermatitis 2014;70(Suppl. 1):45

14 Athanasiadis GI, Pfab F, Klein A, Braun-Falco M, Ring J, Ollert M. Erythema multiforme due to contact with laurel oil. Contact Dermatitis 2007;57:116-118

15 Hausen BM. Lorbeer-Allergie Ursache, Wirkung und Folgen der äusserlichen Anwendung eines sogenannten Naturheilmittels. Dtsch Med Wschr 1985;110: 634-638

16 Özden MG, Öztaş P, Öztaş MO, Önder M. Allergic contact dermatitis from *Laurus nobilis* (laurel) oil. Contact Dermatitis 2001;45:178

17 Reutemann P, Ehrlich A. Neem oil: an herbal therapy for alopecia areata causes dermatitis. Dermatitis 2008;19:E12-E15

18 Lapeere H, Boone B, Verhaeghe E, Ongenae K, Lambert J. Contact dermatitis caused by lovage (*Levisticum officinalis*) essential oil. Contact Dermatitis 2013;69:181-182

19 Coulson IH, Ali Khan AS. Facial 'pillow' dermatitis due to lavender oil allergy. Contact Dermatitis 1999;41:111

20 Coutts I, Shaw S, Orton D. Patch testing with pure tea tree oil - 12 months experience. Br J Dermatol 2002;147(Suppl. 62):70

21 Nardelli A, Drieghe J, Claes L, Boey L, Goossens A. Fragrance allergens in 'specific' cosmetic products. Contact Dermatitis 2011;64:212-219

22 Christoffers WA, Blömeke B, Coenraads P-J, Schuttelaar M-LA. Co-sensitization to ascaridole and tea tree oil. Contact Dermatitis 2013;69:187-189

23 Travassos AR, Claes L, Boey L, Drieghe J, Goossens A. Non-fragrance allergens in specific cosmetic products. Contact Dermatitis 2011;65:276-285

24 Williams JD, Nixon RL, Lee A. Recurrent allergic contact dermatitis due to allergen transfer by sunglasses. Contact Dermatitis 2007;57:120-121

25 Vilaplana J, Romaguera C, Grimalt F. Contact dermatitis from geraniol in Bulgarian rose oil. Contact Dermatitis 1991;24:301

26 Penchalaiah K, Handa S, Lakshmi SB, Sharma VK, Kumar B. Sensitizers commonly causing allergic contact dermatitis from cosmetics. Contact Dermatitis 2000;43:311-313

27 Tran A, Pratt M, DeKoven J. Acute allergic contact dermatitis of the lips from peppermint oil in a lip balm. Dermatitis 2010;21:111-115

28 Newsham J, Rai S, Williams JDL. Two cases of allergic contact dermatitis to neroli oil. Br J Dermatol 2011;165(Suppl.1):76

29 Larsen WG. Cosmetic dermatitis due to a perfume. Contact Dermatitis 1975;1:142-145

30 Zedlitz S, Kaufmann R, Boehncke W. Allergic contact dermatitis from black cumin (*Nigella sativa*) oil-containing ointment. Contact Dermatitis 2002;46:188

31 Davies MG, Hodgson GA, Evans E. Contact dermatitis from an ostomy deodorant. Contact Dermatitis 1978;4:11-13

32 Starke JC. Photoallergy to sandalwood oil. Arch Dermatol 1967;96:62-63

33 Scheinman PL. Is it really fragrance free? Am J Cont Derm 1997;8:239-242

34 Chang Y-C, Maibach HI. Pseudo flautist's lip: allergic contact cheilitis from geraniol. Contact Dermatitis 1997;37:39

35 Spier HW, Sixt I. Lorbeer als Träger eines wenig beachteten kontaktekzemotogenen Allergens. Derm Wochenschr 1953;128:805-810

36 Brandao FM. Occupational allergy to lavender oil. Contact Dermatitis 1986;15:249-250

37 Ménard E. Les dermatoses professionelles. Concours Médicale 1961;83:4308-4311

38 Varma S, Blackford S, Statham BN, Blackwell A. Combined contact allergy to tea tree oil and lavender oil complicating chronic vulvovaginitis. Contact Dermatitis 2000;42:309-310

39 Serrano G, Pujol C, Cuadra J, Gallo S, Aliaga A. Riehl's melanosis: Pigmented contact dermatitis caused by fragrances. J Am Acad Dermatol 1989;21:1057-1060

40 Magnusson B, Wilkinson DS. Cinnamic aldehyde in toothpaste. 1. Clinical aspects and patch tests. Contact Dermatitis 1975;1:70-76

41 Silvers SH. Stomatitis and dermatitis venenata with purpura, resulting from oil of cloves and oil of cassia. Dental Items of Interest 1939;61:649-651. Data cited in ref. 40

42 Laubach JL, Malkenson FD, Ringrose EJ. Cheilitis caused by cinnamon (cassia) oil in toothpaste. JAMA 1953;152:404-405. Data cited in ref. 40

43 Drake TE, Maibach HI. Allergic contact dermatitis and stomatitis caused by a cinnamic aldehyde-flavored toothpaste. Arch Dermatol 1976;112:202-203

44 Millard LG. Acute contact sensitivity to a new toothpaste. J Dentistry 1973;1:168-170

45 Millard LG. Contact sensitivity to toothpaste. Brit Med J 1973;1:676

46 Cummer CL. Dermatitis due to oil of cinnamon. Arch Dermatol Syphilol 1940;42:674-675

47 Dooms-Goossens A, Degreef H, Holvoet C, Maertens M. Turpentine-induced hypersensitivity to peppermint oil. Contact Dermatitis 1977;3:304-308

48 Fleming CJ, Forsyth A. D5 patch test reactions to menthol and peppermint. Contact Dermatitis 1998;38:337

49 Freeman S, Stephens R. Cheilitis: Analysis of 75 cases referred to a contact dermatitis clinic. Am J Cont Derm 1999;10:198-200

50 Downs AMR, Lear JT, Sansom JE. Contact sensitivity in patients with oral symptoms. Contact Dermatitis 1998; 39:258-259

51 Hjorth N, Jervoe P. Allergisk Kontaktstomatitis og Kontaktdermatitis fremkaldt of smagsstoffer i tandpasta. Tandlaegebladet 1967;71:937-942. Data cited in ref. 40

52 Clayton R, Orton D. Contact allergy to spearmint oil in a patient with oral lichen planus. Contact Dermatitis 2004;51:314-315

53 Skrebova N, Brocks K, Karlsmark T. Allergic contact cheilitis from spearmint oil. Contact Dermatitis 1998;39:35-36

54 Worm M, Jeep S, Sterry W, Zuberbier T. Perioral contact dermatitis caused by L-carvone in toothpaste. Contact Dermatitis 1998;38:338

55 Sainio E-L, Kanerva L. Contact allergens in toothpastes and a review of their hypersensitivity. Contact Dermatitis 1995;33:100-105

56 Grattan CEH, Peachy RD. Contact sensitization to toothpaste flavouring. J Royal Coll Gen Pract 1985;35:498. data cited in ref. 55

57 Baer ON. Toothpaste allergies. J Clin Pediatr Dent 1992;16:230-231. Data cited in ref. 55

58 Loveman AB. Stomatitis venenata. Report of a case of sensitivity of the mucous membranes and the skin to oil of anise. Arch Derm Syph 1938;37:70-81

59 Nardelli A, D'Hooge E, Drieghe J, Dooms M, Goossens A. Allergic contact dermatitis from fragrance components in specific topical pharmaceutical products in Belgium. Contact Dermatitis 2009;60:303-313

60 Devleeschouwer V, Roelandts R, Garmyn M, Goossens A. Allergic and photoallergic contact dermatitis from ketoprofen: results of (photo) patch testing and follow-up of 42 patients. Contact Dermatitis 2008;58:159-166

61 Bhushan M, Beck MH. Allergic contact dermatitis from tea tree oil in a wart paint. Contact Dermatitis 1997;36:117-118

62 Foti C, Conserva A, Antelmi A, Lospalluti L, Angelini G. Contact dermatitis from peppermint and menthol in a local action transcutaneous patch. Contact Dermatitis 2003;49:312-313

63 Matthieu L, Meuleman L, van Hecke E, Blondeel A, Dezfoulian B, Constandt L, Goossens A. Contact and photocontact allergy to ketoprofen. The Belgian experience. Contact Dermatitis 2004;50:238-241

64 McGeorge BCL, Steele MC. Allergic contact dermatitis of the nipple from Roman chamomile ointment. Contact Dermatitis 1991;24:139-140

65 Giordano-Labadie F, Schwarze HP, Bazex J. Allergic contact dermatitis from chamomile used in phytotherapy. Contact Dermatitis 2000;42:247

66 Lauriola MM, De Bitonto A, Sena P. Allergic contact dermatitis due to cinnamon oil in galenic vaginal suppositories. Acta Derm Venereol 2010;90:187-188

67 Knöll R, Ulrich R, Spallek W. Allergic contact eczema to etofenamate and dwarf pine oil. Sportverletz Sportschaden 1990;4(2):96-98 (article in German)

68 Noiles K, Pratt M. Contact dermatitis to Vicks VapoRub. Dermatitis 2010;21:167-169

69 Vilaplana J, Romaguera C. Allergic contact dermatitis due to eucalyptol in an anti-inflammatory cream. Contact Dermatitis 2000;43:118

70 Eun HC, Lee AY. Contact dermatitis due to Madecassol. Contact Dermatitis 1985;13:310-313

71 Zina G, Bony G. Phenergan cream (role of base constituents). Contact Dermatitis Newsletter 1969;6:117

72 Le Coulant P, Texier L, Malleville J, Doussy NN. Sensibilization à une crème antihistaminique. Bull Soc Franç Derm Syph 1964;71:234-237

73 Trattner A, David M, Lazarov A. Occupational contact dermatitis due to essential oils. Contact Dermatitis 2008;58:282-284

74 Gunatheesan S, Tam MM, Tate B, Tversky J, Nixon R. Retrospective study of oral lichen planus and allergy to spearmint oil. Australas J Dermatol 2012;53:224-228

75 Cahill J, Gunatheesan S, Tam M, Tate B, Nixon R. Oral lichen planus and allergy to spearmint oil. Contact Dermatitis 2012;66 (Suppl. 2):38 (FC1.03)

76 Khanna M, Qasem K, Sasseville D. Allergic contact dermatitis to tea tree oil with erythema multiforme-like id reaction. Dermatitis 2000;11:238-242

77 Gelot P, Bara-Passot C, Gimenez-Arnau E, Beneton N, Maillard H, Celerier P. Bullous drug eruption with *Nigella sativa* oil. Ann Dermatol Venereol 2012;139:287-291

78 Nosbaum A, Ben Said B, Halpern S-J, Nicolas J-F, Bérard F. Systemic allergic contact dermatitis to black cumin essential oil expressing as generalized erythema multiforme. Eur J Dermatol 2011;21:447-448

79 Perrett CM, Evans AV, Russell-Jones R. Tea tree oil dermatitis associated with linear IgA disease. Clin Exp Dermatol 2003;28:167-170

80 Gad El-Rab MO, Al-Sheikh OA. Is the European standard series suitable for patch testing in Riyadh, Saudi Arabia? Contact Dermatitis 1995;33:310-314

81 Adişen E, Önder M. Allergic contact dermatitis from *Laurus nobilis* oil induced by massage. Contact Dermatitis 2007;56:360-361

82 Leifer W. Contact dermatitis due to cinnamon. Recurrence of dermatitis following oral administration of cinnamon oil. Arch Dermatol Syphylol 1951;64:52-55

83 de Groot AC. Airborne allergic contact dermatitis from tea tree oil. Contact Dermatitis 1996;35:304-305

84 Schaller M, Korting HC. Allergic airborne contact dermatitis from essential oils used in aromatherapy. Clin Exp Dermatol 1995;20:143-145

85 Franz H, Frank R, Rytter M, Haustein UF. Allergic contact dermatitis due to cedarwood oil after dermatoscopy. Contact Dermatitis 1998;38:182-183

86 Temesvári E, Podányi B, Pónyai G, Németh I. Fragrance sensitization caused by temporary henna tattoo. Contact Dermatitis 2002;47:240

87 Garcia-Abujeta JL, de Larramendi CH, Pomares Berna J, Munoz Palomino E. Mud bath dermatitis due to cinnamon oil. Contact Dermatitis 2005;52:234

88 Martins C, Gonçalo M, Gonçalo S. Allergic contact dermatitis from dipentene in wax polish. Contact Dermatitis 1995;33:126-127

89 Crawford GH, Katz KA, Ellis E, James WD. Use of aromatherapy products and increased risk of hand dermatitis in massage therapists. Arch Dermatol 2004;140:991-996

90 Uter W, Schnuch A, Geier J, Pfahlberg A, Gefeller O. IVDK study group; Information Network of Departments of Dermatology. Association between

occupation and contact allergy to the fragrance mix: a multifactorial analysis of national surveillance data. Occup Environ Med 2001;58:392-398

91 Romaguera C, Vilaplana J. Occupational contact dermatitis from ylang-ylang oil. Contact Dermatitis 2000;43:251

92 Van der Valk PG, de Groot AC, Bruynzeel DP, Coenraads PJ, Weijland JW. Allergic contact eczema due to tea tree oil. Ned Tijdschr Geneeskd 1994;138:823-825

93 Jung P, Sesztak-Greinecker G, Wantke F, Götz M, Jarisch R, Hemmer W. Mechanical irritation triggering allergic contact dermatitis from essential oils in a masseur. Contact Dermatitis 2006;54:297-299

94 Keane FM, Smith HR, White IR, Rycroft RJG. Occupational allergic contact dermatitis in two aromatherapists. Contact Dermatitis 2000;43:49-51

95 Selvaag E, Holm J, Thune P. Allergic contact dermatitis in an aromatherapist with multiple sensitizations to essential oils. Contact Dermatitis 1995;33:354-355

96 Boonchai W, Lamtharachai P, Sunthonpalin P. Occupational allergic contact dermatitis from essential oils in aromatherapists. Contact Dermatitis 2007;56:181-182

97 Cockayne SE, Gawkrodger DJ. Occupational contact dermatitis in an aromatherapist. Contact Dermatitis 1997;37:306-307

98 Sánchez-Pérez J, García-Díez A. Occupational allergic contact dermatitis from eugenol, oil of cinnamon and oil of cloves in a physiotherapist. Contact Dermatitis 1999;41:346-347

99 De Mozzi P, Johnston GA. An outbreak of allergic contact dermatitis caused by citral in beauticians working in a health spa. Contact Dermatitis 2014;70:377-379

100 Bleasel N, Tate B, Rademaker M. Allergic contact dermatitis following exposure to essential oils. Australas J Dermatol 2002;43:211-213

101 Schubert HJ. Skin diseases in workers at a perfume factory. Contact Dermatitis 2006;55:81-83

102 Audicana M, Bernaola G. Occupational contact dermatitis from citrus fruits: Lemon essential oils. Contact Dermatitis 1994;31:183-185

103 Mendelsohn HV. Dermatitis from lemon grass oil (*Cymbopogon citratus* or *Andropogon citratus*). Arch Dermatol 1944;50:34-35

104 Calnan CD. Lovage sensitivity. Contact Dermatitis Newsletter 1969;5:99

105 Rudzki E, Rebandel P, Grzywa Z. Occupational dermatitis from cosmetic creams. Contact Dermatitis 1993;29:210

106 Kanerva L, Estlander T, Jolanki R. Occupational allergic contact dermatitis caused by ylang-ylang oil. Contact Dermatitis 1995;33:198-199

107 Morris GE. Dermatoses among food handlers. Ind Med Surg 1954;23:343

108 Peltonen L, Wickstrom G, Vaahtoranta M. Occupational dermatoses in the food industry. Dermatosen 1985;33:166-169

109 Garcia-Bravo B, Pérez Bernal A, Garcia-Hernandez MJ, Camacho F. Occupational contact dermatitis from anethole in food handlers. Contact Dermatitis 1997;37:38

110 Vente C, Fuchs T. Contact dermatitis due to oil of turpentine in a porcelain painter. Contact Dermatitis 1997;37:187

111 Zacher KD, Ippen H. Kontaktekzem durch Bergamottöl. Derm Beruf Umwelt 1984;32:95-97

112 Miller J. Cheilitis from sensitivity to oil of cinnamon present in bubble gum. JAMA 1941;116:131-132

113 Nethercott JR, Holness DL. Occupational dermatitis in food handlers and bakers. J Am Acad Dermatol 1989;21:485-490

114 Gutman SG, Somov BA. Allergic reactions caused by components of perfumery preparations. Vestnik Dermatologii i Venerologii 1968;42:62 (in Russian)

115 Rothe A, Heine A, Rebohle E. Oil from juniper berries as an occupational allergen for the skin and respiratory tract. Berufsdermatosen 1973;21:11-16 (in German)

116 Meynadier JM, Meynadier J, Peyron JL, Peyron L. Formes cliniques des manifestations cutanées d'allergie aux parfums. Ann Dermatol Venereol 1986;113:31-39

117 Uter W, Schmidt E, Geier J, Lessmann H, Schnuch A, Frosch P. Contact allergy to essential oils: current patch test results (2000–2008) from the Information Network of Departments of Dermatology (IVDK). Contact Dermatitis 2010;63:277-283

118 Mitchell JC. Contact hypersensitivity to some perfume materials. Contact Dermatitis 1975;1:197-199

119 Nardelli A, Thijs L, Janssen K, Goossens A. *Rosa centifolia* in a 'non-scented' moisturizing body lotion as a cause of allergic contact dermatitis. Contact Dermatitis 2009;61:306-309

120 de Groot AC, Coenraads PJ, Bruynzeel DP, Jagtman BA, van Ginkel CJW, Noz K, van der Valk PGM et al. Routine patch testing with fragrance chemicals in The Netherlands. Contact Dermatitis 2000;42:184-185

121 Frosch PJ, Johansen JD, Menné T, Pirker C, Rastogi SC, Andersen KE et al. Further important sensitizers in patients sensitive to fragrances. II. Reactivity to essential oils. Contact Dermatitis 2002;47:279-287

122 Treudler R, Richter G, Geier J, Schnuch A, Orfanos CE, Tebbe B. Increase in sensitization to oil of turpentine: recent data from a multicenter study on 45,005 patients from the German-Austrian Information Network of Departments of Dermatology (IVDK). Contact Dermatitis 2000;42:68-73

123 Paulsen E, Andersen KE. Colophonium and Compositae mix as markers of fragrance allergy: Cross-reactivity between fragrance terpenes, colophonium and Compositae plant extracts. Contact Dermatitis 2005;53:285-291

124 Hayakawa R, Matsunaga K, Arima Y. Depigmented contact dermatitis due to incense. Contact Dermatitis 1987;16:272-274

125 de Groot AC, Weijland JW. Systemic contact dermatitis from tea tree oil. Contact Dermatitis 1992;27:279-280

126 Vilaplana J, Romaguera C, Grimalt F. Contact dermatitis from geraniol in Bulgarian rose oil. Contact Dermatitis 1991;24:301

127 Karlberg A-T, Börje A, Johansen JD, Lidén C, Rastogi S, Roberts D, et al. Activation of non-sensitizing or low-sensitizing fragrance substances into potent sensitizers – prehaptens and prohaptens. Contact Dermatitis 2013;69:323-334

128 Rudzki E, Grzywa Z. Dermatitis from propolis. Contact Dermatitis 1983;9:40-45

129 Nakayama H, Hanaoka H, Ohshiro A. Allergen Controlled System (ACS). Tokyo, Japan: Kanehara Shuppan, 1974:42. Data cited in ref. 118

130 Pesonen M, Suomela S, Kuuliala O, Henriks-Eckerman M-L, Aalto-Korte K. Occupational contact dermatitis caused by D-limonene. Contact Dermatitis 2014;71:273-279

131 Juarez A, Goiriz R, Sanchez-Perez J, Garcia-Diez A. Disseminated allergic contact dermatitis after exposure to a topical medication containing geraniol. Dermatitis 2008;19:163

132 Wetter DA, Yiannias JA, Prakash AV, Davis MD, Farmer SA, el-Azhary RA, et al. Results of patch testing to personal care product allergens in a standard series and a supplemental cosmetic series: an analysis of 945 patients from the Mayo Clinic Contact Dermatitis Group, 2000-2007. J Am Acad Dermatol 2010;63:789-798

133 Schäfer T, Böhler E, Ruhdorfer S, Weigl L, Wessner D, Filipiak B, et al. Epidemiology of contact allergy in adults. Allergy 2001;56:1192-1196

134 Pesonen M, Suomela S, Kuuliala O, Henriks-Eckerman M-L, Aalto-Korte K. Occupational contact dermatitis caused by D-limonene. Contact Dermatitis 2014;71:273-279

Chapter 4 CHEMICALS IDENTIFIED IN ESSENTIAL OILS WHICH HAVE CAUSED CONTACT ALLERGY

In this chapter, a list of over 110 chemicals identified in essential oils which have reportedly caused contact allergy or allergic contact dermatitis is presented (Table 4.1). Some are well-known allergens; others have caused allergic reactions infrequently, rarely, or even only once. The list includes some compounds that are known allergens in essential oils per se, for example, terpinolene, ascaridole, α-terpinene, 1,2,4-trihydroxymenthane, α-phellandrene, limonene and myrcene in tea tree oil; α-pinene, δ3-carene hydroperoxides and limonene in turpentine oil; geraniol in geranium and rose oils; cinnamic aldehyde in cassia and cinnamon oils; menthol in peppermint oil; carvone in spearmint oil and eugenol in clove oils. The majority of chemicals, however, have caused contact allergy only by their presence in products other than essential oils. When treating patients with allergic reactions to essential oils, the (possible) composition of the oils should be checked first in the individual oil files (Chapters 5.1-5.93). Following that, the list presented here may give some direction to facilitate the search for the responsible allergen(s) in these patients, especially when lack of concomitant reactions to oil ingredients and the nature of the oil composition fail to give proper guidance.

A number of chemicals reported to be present in essential oils may not have been identified correctly; some have apparently not been found in nature so far and are known to be synthetic compounds. Examples include the esters of phthalic acid (dibutyl phthalate, bis-(2-ethylhexyl)phthalate (dioctyl phthalate), diethyl phthalate, dimethyl phthalate), butylphenyl methylpropional (Lilial®) and hydroxyisohexyl 3-cyclohexene carboxaldehyde, trade name Lyral. Nevertheless, as it is impossible to definitely *exclude* their presence in nature, we have opted to include these chemicals in the list. In addition, these chemicals may have entered the oils as a result of contamination or adulteration (and have been identified correctly).

In Table 4.1 the following data of the chemicals are presented: name of the compound, CAS number, availability as commercial test preparation (for suppliers and test concentrations see Chapter 3, Table 4), important synonyms, sometimes some additional information and one or more relevant literature references. It falls outside the scope of this book to provide extensive additional data on these chemicals such as chemical/IUPAC names, other synonyms, EINECS numbers, chemical formulas, chemical structures, chemical classes, toxicology reviews, more extensive literature references et cetera; this will be the subject of a planned future publication (A.C. de Groot. *Cosmetic Allergy – Cosmetic Allergens*).

LITERATURE

1 Handley J, Burrows D. Allergic contact dermatitis from the synthetic fragrances Lyral and acetyl cedrene in separate underarm deodorant preparations. Contact Dermatitis 1994;31:288-290

2 Frosch PJ, Pilz B, Andersen KE, Burrows D, Camarasa JG, Dooms-Goosens A, et al. Patch testing with fragrances: results of a multicenter study of the European Environmental and Contact Dermatitis Research Group with 48 frequently used constituents of perfumes. Contact Dermatitis 1995;33:333-342

3 Larsen W, Nakayama H, Fischer T, Elsner P, Frosch P, Burrows D, et al. Fragrance contact dermatitis: a worldwide multicenter investigation (Part II). Contact Dermatitis 2001;44:344-346

4 Mann J, McFadden JP, White JML, White IR, Banerjee P. Baseline series fragrance markers fail to predict contact allergy. Contact Dermatitis 2014;70:276-281

5 Uter W, Geier J, Frosch P, Schnuch A. Contact allergy to fragrances: current patch test results (2005–2008) from the Information Network of Departments of Dermatology. Contact Dermatitis 2010;63:254-261

6 Andersen KE. Contact allergy to toothpaste flavors. Contact Dermatitis 1978;4:195-198

7 Rudzki E, Grzywa Z. Sensitizing and irritating properties of star anise oil. Contact Dermatitis 1976;2:305-306

8 Larsen WG, Nakayama H, Lindberg M, Fischer T, Elsner P, Burrows D, et al. Fragrance contact dermatitis: a worldwide multicenter investigation (Part I). Am J Contact Dermat 1996;7:77-83

9 Hausen BM. Evaluation of the main contact allergens in oxidized tea tree oil. Dermatitis 2004;15:213-214

10 Knight TE, Hausen BM. Melaleuca oil (tea-tree oil) dermatitis. J Am Acad Dermatol 1994;30:423-427

11 Christoffers WA, Blömeke B, Coenraads P-J, Schuttelaar M-LA. The optimal patch test concentration for ascaridole as a sensitizing component of tea tree oil. Contact Dermatitis 2014;71:129-137

12 Pirker C, Hausen BM, Uter W, Hillen U, Brasch J, Bayerl C, et al. Sensitization to tea tree oil in Germany and Austria. A multicenter study of the German Contact Dermatitis group. J Dtsch Dermatol Ges 2003;1:629-634

13 Francalanci S, Sertoli A, Giorgini S, Pigatto P, Santucci B, Valsecchi R. Multicentre study of allergic contact cheilitis from toothpastes. Contact Dermatitis 2000; 43:216-222

14 Balato N, Leimbo G, Nappa D, Ayala F. Allergic cheilitis to azulene. Contact Dermatitis 1985;13:39-40

15 Hausen BM. Contact allergy to balsam of Peru. II. Patch test results in 102 patients with selected balsam of Peru constituents. Am J Contact Derm 2001;12:93-102

Table 4.1 Chemicals identified in essential oils which have caused contact allergy/allergic contact dermatitis

Chemical	CAS	CTP	Synonyms and additional information	Refs.
Acetyl cedrene	32388-55-9		Trade name: Vertofix; not found in nature so far	1,2
Ambrettolide	7779-50-2		Synonym: ω-6-hexadecenlactone	3
(*E*)-Amylcinnamyl alcohol		+	The commercial test preparation is α-amylcinnamic alcohol	4,5
Anethole	104-46-1	+		6,7
Anisyl alcohol	1331-81-3	+		4,5,8
Aromadendrene	489-39-4			9,10
Ascaridole	512-85-6			9,11,12
Azulene	275-51-4			13,14
Benzaldehyde	100-52-7	+		5
Benzoic acid	65-85-0	+		15,16
Benzyl acetate	140-11-4			17
Benzyl alcohol	100-51-6	+		4,5,15,18
Benzyl benzoate	120-51-4	+		4,5,15
Benzyl cinnamate	103-41-3	+		4,5,15
Benzyl propionate	122-63-4			96
Benzyl salicylate	118-58-1	+		4,8,15
Bisabolol	515-69-5			19,20
Bis-(2-ethylhexyl) phthalate	117-81-7	+	Not found in nature so far	104
Butylphenyl methylpropional	80-54-6	+	Trade name: Lilial; not found in nature so far	4
Camphor	76-22-2	+		21,22,23
δ3-Carene	13466-78-9		The allergen is oxidized δ3-carene	24,25,26
Carvacrol	499-75-2			27
Carvone	99-49-0	+		6,9,28,29
β-Caryophyllene	87-44-5		Auto-oxidation increases the sensitizing potency (30,33)	31,32,34
Caryophyllene oxide	1139-30-6			31
1,8-Cineole	470-82-6			35
Cinnamic acid	621-82-9			15
Cinnamic aldehyde	104-55-2	+	Synonyms: cinnamaldehyde, cinnamal; present in the fragrance mix I	4,5,36,37
Cinnamyl alcohol	104-54-1	+	Present in the fragrance mix I	5,15,36
Cinnamyl benzoate	5320-75-2			38
Cinnamyl cinnamate	122-69-0			15
Citral	5392-40-5	+	Combination of neral and geranial; present in the fragrance mix II	39,40,41 42,43
Citronellal	106-23-0	+		44
Citronellol	106-22-9	+	Present in the fragrance mix II; auto-oxidation leads to more sensitizing hydroperoxides (45)	4,36,42
Coniferyl alcohol	458-35-5			15
Coniferyl benzoate	4159-29-9			15
Costunolide	553-21-9		Present in the sesquiterpene lactone mix	46
Coumarin	91-64-5	+	Present in the fragrance mix II	4,36,42
Cuminaldehyde	122-03-2			47
p-Cymene	99-87-6			10
β-Damascone			Contact allergy was to a mixture of α- and β-damascone	32
Dehydrocostus lactone	477-43-0	+	Present in the sesquiterpene lactone mix	48
Dibutyl phthalate	84-74-2	+	Not found in nature so far	101
Diethyl phthalate	84-66-2	+	Not found in nature so far	102,103
Dihydrocoumarin	119-84-6			49
Dimethyl phthalate	131-11-3	+	Not found in nature so far	103
Eugenol	97-53-0	+	Present in the fragrance mix I	4,5,15,36
Falcarinol	21852-80-2			50,51
Farnesol	4602-84-0	+	Present in the fragrance mix II	36,37,42
Geranial	141-27-5		Present in citral (with neral)	40,41
Geraniol	106-24-1	+	Present in the fragrance mix I; auto-oxidation increases the sensitizing potency (30,52) and leads to the formation of neral and geranial (40)	5,36,37 40,41
Geranyl acetate	105-87-3			44
Guaiazulene	489-84-9			14,53
Heptanal	111-71-7			54
Hexadecanolide	109-29-5			3,55
(*Z*)-3-Hexenyl salicylate	65405-77-8			56

Table 4.1 Chemicals identified in essential oils which have caused contact allergy/allergic contact dermatitis (*continued*)

Chemical	CAS	CTP	Synonyms and additional information	Refs.
α-Hexylcinnamaldehyde	101-86-0	+	Not found in nature so far; present in the fragrance mix II	36,37,42
Hydroxycitronellal	107-75-5	+	Not found in nature so far; present in the fragrance mix I	5,36,37
Hydroxycitronellol	107-74-4		Not found in nature so far	57
Hydroxyisohexyl 3-cyclohexene carboxaldehyde		+	Trade name: Lyral®; not found in nature so far; present in the fragrance mix II	4,36,97,98, 99
α-Ionone	127-41-3		Patients were tested with mixed ionone isomers (47,58)	47,58
β-Ionone	79-77-6		Patients were tested with mixed ionone isomers (47,58)	47,58
Isoeugenol	97-54-1	+	Present in the fragrance mix I	5,36,37
Isoeugenyl acetate	93-29-8			59
Isopulegol	89-79-2			17
Isosafrole	120-58-1			96
Isothymol	4427-56-9			60
Limonene	138-86-3	+	Auto-oxidation increases the sensitizing potency of D-limonene (30) by forming limonene hydroperoxides (63)	37,61,62,64,65
Limonene oxide	1195-92-2			66
Linalool	78-70-6	+	Auto-oxidation increases the sensitizing potency (30) by forming hydroperoxides	4,67,68
Linalyl acetate	115-95-7		Auto-oxidation increases the sensitizing potency (30)	69,70,87
Menthol	89-78-1	+		71,72,73
o-Methoxycinnamaldehyde (2-)	1504-74-1			38
7-Methoxycoumarin	531-59-9		Synonym: herniarin	74
8-Methoxypsoralen	298-81-7			75
Methyl *p*-anisate	121-98-2			76
Methyl anthranilate	134-20-3	+		77,78
Methyl cinnamate	103-26-4			15,79
Methyl dihydrojasmonate	24851-98-7		Synonym: hedione	32
Methyl eugenol	93-15-2			57
Methylionone	1335-46-2	+	The commercial test preparation is γ-methylionone (α-isomethyl ionone); the patient reacted to 'methylionone γ', containing 65-75% α-methylionone (58)	58
Methyl isoeugenol	93-16-3			57
Methyl salicylate	119-36-8	+		80,81
Musk ambrette	123-69-3	+	Not found in nature so far	82,83,84
Myrcene	123-35-3			9,12,31
Neral	106-26-3		Present in citral (with geranial)	40,41
Nerol	106-25-2			57
Nerolidol	7212-44-4			15
Nonanal	124-19-6			54
Nonanol	28473-21-4			54
Nopyl acetate	128-51-8			47
Octanol	29063-28-3			54
α-Phellandrene	99-83-2			9,12,85
2-Phenethyl alcohol	60-12-8			17,47
Phenylacetaldehyde	122-78-1			76,86
α-Pinene	80-56-8	+	Oxidation increases the sensitizing potential	26,85,87
β-Pinene	127-91-3			26,44,82
Piperitone	89-81-6			100
Piperonal	120-57-0		Synonym: heliotropine	17,32
Propylidene phthalide	17369-59-4			76
Pulegone	89-82-7			100
Retinyl (vitamin A) acetate	127-47-9		Not found in nature so far	105
Sabinene	3387-41-5			9
Safrole	94-59-7			7
Salicylaldehyde	90-02-8	+		5,88
Santalol				89-92
α-Terpinene	99-86-5		Auto-oxidation increases the sensitizing potency (30,95)	9,12
Terpinen-4-ol	562-74-3			9,93
α-Terpineol	98-55-5			82,87,94

Table 4.1 Chemicals identified in essential oils which have caused contact allergy/allergic contact dermatitis (*continued*)

Chemical	CAS	CTP	Synonyms and additional information	Refs.
Terpinolene	586-62-9			9,12,25
Terpinyl acetate	8007-35-0			17
Thymol	89-83-8	+		23,36,95
1,2,4-Trihydroxymenthane				9,12
Vanillin	121-33-5	+		5
Viridiflorene	21747-46-6		Synonym: ledene	9,12

CTP: Commercial test preparation available (Chapter 3, Table 4)

16 Jacob SE, Stechschulte S. Eyelid dermatitis associated with balsam of Peru constituents: benzoic acid and benzyl alcohol. Contact Dermatitis 2008;58:111-112

17 Larsen WG. Perfume dermatitis. A study of 20 patients. Arch Dermatol 1977;113:623-626

18 Curry EJ, Warshaw EM. Benzyl alcohol allergy: importance of patch testing with personal products. Dermatitis 2005;16:203-208

19 Jacob SE, Matiz C, Herro EM. Compositae-associated allergic contact dermatitis from bisabolol. Dermatitis 2011;22:102-105

20 Russell K, Jacob SE. Bisabolol. Dermatitis 2010;21:57-58

21 Stevenson OE, Finch TM. Allergic contact dermatitis from rectified camphor oil in Earex ear drops. Contact Dermatitis 2003;49:51

22 Noiles K, Pratt M. Contact dermatitis to Vicks VapoRub. Dermatitis 2010;21:167-169

23 Nardelli A, D'Hooghe E, Drieghe J, Dooms M, Goossens A. Allergic contact dermatitis from fragrance components in specific topical pharmaceutical products in Belgium. Contact Dermatitis 2009;60:303-313

24 Hellerstrom S, Thyresson N, Blohm SG, Widmark G. On the nature of the eczematogenic component of oxidized delta 3-carene. J Invest Dermatol 1955;24:217-224

25 Castelain PY, Camoin JP, Jouglard J. Contact dermatitis to terpene derivatives in a machine cleaner. Contact Dermatitis 1980;6:358-360

26 Romaguera C, Alomar A, Conde-Salazar L, Camarasa JMG, Grimalt F, Martin Pascual A, et al. Turpentine sensitization. Contact Dermatitis 1986;14:197

27 Andersen A. Final report on the safety assessment of sodium *p*-chloro-*m*-cresol, *p*-chloro-*m*-cresol, chlorothymol, mixed cresols, *m*-cresol, *o*-cresol, *p*-cresol, isopropyl cresols, thymol, *o*-cymen-5-ol, and carvacrol. Int J Toxicol 2006;25 (Suppl. 1):29-127

28 Quertermous J, Fowler JF Jr. Allergic contact dermatitis from carvone in hair conditioners. Dermatitis 2010;21:116-117

29 Paulsen E, Andersen KE, Carsen L, Egsgaard H. Carvone: an overlooked contact allergen cross-reacting with sesquiterpene lactones? Contact Dermatitis 1993;29:138-143

30 Karlberg A-T, Börje A, Johansen JD, Lidén C, Rastogi S, Roberts D, et al. Activation of non-sensitizing or low-sensitizing fragrance substances into potent sensitizers – prehaptens and prohaptens. Contact Dermatitis 2013;69:323-334

31 Matura M, Sköld M, Börje A, Andersen KE, Bruze M, Frosch P, et al. Selected oxidized fragrance terpenes are common contact allergens. Contact Dermatitis 2005;52:320-328

32 Frosch PJ, Johansen JD, Menné T, Pirker C, Rastogi SC, Andersen KE, et al. Further important sensitizers in patients sensitive to fragrances. II. Reactivity to essential oils. Contact Dermatitis 2002;47:279-287

33 Sköld M, Karlberg AT, Matura M, Börje A. The fragrance chemical betacaryophyllene—air oxidation and skin sensitization. Food Chem Toxicol 2006;44:538-545

34 Paulsen E, Andersen KE. Colophonium and Compositae mix as markers of fragrance allergy: Cross-reactivity between fragrance terpenes, colophonium and Compositae plant extracts. Contact Dermatitis 2005;53:285-291

35 de Groot AC, Weyland JW. Systemic contact dermatitis from tea tree oil. Contact Dermatitis 1992;27:279-280

36 Nardelli A, Carbonez A, Drieghe J, Goossens A. Results of patch testing with fragrance mix 1, fragrance mix 2, and their ingredients, and *Myroxylon pereirae* and colophonium, over a 21-year period. Contact Dermatitis 2013;68:307-313

37 Heisterberg MV, Menné T, Johansen JD. Contact allergy to the 26 specific fragrance ingredients to be declared on cosmetic products in accordance with the EU cosmetics directive. Contact Dermatitis 2011;65:266-275

38 Malten KE. Four bakers showing positive patch-tests to a number of fragrance materials, which can also be used as flavors. Acta Dermatovenereologica 1979;59 (Suppl.85):117-121

39 De Mozzi P, Johnston GA. An outbreak of allergic contact dermatitis caused by citral in beauticians working in a health spa. Contact Dermatitis 2014;70:377-379

40 Hagvall L, Christensson JB. Cross-reactivity between citral and geraniol – can it be attributed to oxidized geraniol? Contact Dermatitis 2014;71:280-288

41 Hagvall L, Karlberg A-T, Brared Christensson J. Contact allergy to air-exposed geraniol: clinical observations and report of 14 cases. Contact Dermatitis 2012;67:20-27

42 Krautheim A, Uter W, Frosch P, Schnuch A, Geier J. Patch testing with fragrance mix II: results of the IVDK 2005–2008. Contact Dermatitis 2010; 63:262-269

43 Heydorn S, Menné T, Andersen KE, Bruze M, Svedman C, White IR, Basketter DA. Citral, a fragrance allergen and irritant. Contact Dermatitis 2003;49:32-36

44 Keil H. Contact dermatitis due to oil of citronellal. J Invest Dermatol 1947;8:327-334

45 Rudbäck J, Hagvall L, Börje A, Nilsson U, Karlberg A-T. Characterization of skin sensitizers from autoxidized citronellol – impact of the terpene structure on the autoxidation process. Contact Dermatitis 2014;70:329-339

46 Le Coz C-J, Lepoittevin J-P. Occupational erythema-multiforme-like dermatitis from sensitization to costus resinoid, followed by flare-up and systemic contact dermatitis from β-cyclocostunolide in a chemistry student. Contact Dermatitis 2001;44:310-311

47 de Groot AC, Liem DH, Nater JP, van Ketel WG. Patch tests with fragrance materials and preservatives. Contact Dermatitis 1985;12: 87-92

48 Paulsen E, Sogaard J, Andersen KE. Occupational dermatitis in Danish gardeners and greenhouse workers (III). Compositae-related skin symptoms. Contact Dermatitis 1998;38:140-146

49 Wilkinson JD, Andersen KE, Camarasa JG, Ducombs G, Frosch P, Lahti A, et al. Preliminary results of effectiveness of two forms of fragrance mix as screening agents for fragrance sensitivity. In: Frosch PJ, Dooms-Goossens A, Lachapelle J-M, Rycroft RJG, ScheperRJ, Eds. Current topics in contact dermatitis. Heidelberg: Springer Verlag, 1989:127-131

50 Machado S, Silva E, Massa A. Occupational allergic contact dermatitis from falcarinol. Contact Dermatitis 2002;47:113-114

51 Hansen L, Hammershøy O, Boll PM. Allergic contact dermatitis from falcarinol isolated from *Schefflera arboricola*. Contact Dermatitis 1986;14:91-93

52 Hagvall L, Backtorp C, Svensson S, Nyman G, Börje A, Karlberg AT. Fragrance compound geraniol forms contact allergens on air exposure. Identification and quantification of oxidation products and effect on skin sensitization. Chem Res Toxicol 2007;20: 807-814

53 Angelini G, Vena GA. Allergic contact cheilitis to guaiazulene. Contact Dermatitis 1984;10:311

54 Larsen WG. Cosmetic dermatitis due to a perfume. Contact Dermatitis 1975;1:142-145

55 An S, Lee AY, Lee CH, Kim D-W, Hahm JH, Kim K-J, et al. Fragrance contact dermatitis in Korea: a joint study. Contact Dermatitis 2005;53:320-323

56 Shaw DW. Allergic contact dermatitis from octisalate and *cis*-3-hexenyl salicylate. Dermatitis 2006;17:152-155

57 Larsen W, Nakayama H, Fischer T, Elsner P, Frosch P, Burrows D, et al. Fragrance contact dermatitis – a worldwide multicenter investigation (Part III). Contact Dermatitis 2002;46:141-144

58 Bernaola G, Escayol P, Fernandez E, Fernandez de Corrés L. Contact dermatitis from methylionone fragrance. Contact Dermatitis 1989;20:71-72

59 White IR, Johansen JD, Arnau EG, Lepoittevin JP, Rastogi S, Bruze M, et al. Isoeugenol is an important contact allergen: can it be safely replaced with isoeugenyl acetate? Contact Dermatitis 1999; 41:272-275

60 Meynadier JM, Meynadier J, Peyron JL, Peyron L. Formes cliniques des manifestations cutanées d'allergie aux parfums. Ann Dermatol Venereol 1986;113:31-39

61 Bråred Christensson J, Andersen KE, Bruze M, Johansen JD, Garcia-Bravo B, et al. An international multicentre study on the allergenic activity of air-oxidized *R*-limonene. Contact Dermatitis 2013;68:214-223

62 Christensson JB, Andersen KE, Bruze M, Johansen JD, Garcia-Bravo B, Gimenez Arnau A, et al. Positive patch test reactions to oxidized limonene: exposure and relevance. Contact Dermatitis 2014;71:264-272

63 Nilsson U, Bergh M, Shao LP, Karlberg A-T. Analysis of contact allergenic compounds in oxidized *d*-limonene. Chromatographia 1996;42:199-205

64 Matura M, Goossens A, Bordalo O, Garcia-Bravo B, Magnusson K, Wrangsjö K, Karlberg A-T. Oxidized citrus oil (*R*-limonene): a frequent sensitizer in Europe. J Am Acad Dermatol 2002;47:709-714

65 Pesonen M, Suomela S, Kuuliala O, Henriks-Eckerman M-L, Aalto-Korte K. Occupational contact dermatitis caused by D-limonene. Contact Dermatitis 2014;71:273-279

66 Matura M, Goossens A, Bordalo O, Garcia-Bravo B, Magnusson K, Wrangsjö K, et al. Patch testing with oxidized *R*-(+)-limonene and its hydroperoxide fraction. Contact Dermatitis 2003;49:15-21

67 Brared Christensson J, Andersen KE, Bruze M, Johansen JD, Garcia-Bravo B, Gimenez Arnau A, et al. Air-oxidized linalool – a frequent cause of fragrance contact allergy. Contact Dermatitis 2012;67:247-259

68 Björkman YA, Hagvall L, Siwmark C, Niklasson B, Karlberg A-T, Bråred Christensson J. Air-oxidized linalool elicits eczema in allergic patients – a repeated open application test study. Contact Dermatitis 2014;70:129-138

69 Sköld M, Hagvall L, Karlberg A-T. Autoxidation of linalyl acetate, the main component of lavender oil, creates potent contact allergens. Contact Dermatitis 2008;58:9-14

70 de Groot AC, Bruynzeel DP, Bos JD, van der Meeren HLM, van Joost T, Jagtman BA, Weyland JW. The allergens In cosmetics. Arch Dermatol 1988;124:1525-1529

71 Morton CA, Garioch J, Todd P, Lamey PJ, Forsyth A. Contact sensitivity to menthol and peppermint in patients with intra-oral symptoms. Contact Dermatitis 1995;32:281-284

72 Lewis FM, Shah M, Gawkrodger DJ. Contact sensitivity to food additives can cause oral and perioral symptoms. Contact Dermatitis 1995;33:429-430

73 Nakagawa S, Tagami H, Aiba S. Erythema multiforme-like generalized contact dermatitis to l-menthol contained in anti-inflammatory medical compresses as an ingredient. Contact Dermatitis 2009;61:178-179

74 Paulsen E, Otkjær A, Andersen KE. The coumarin herniarin as a sensitizer in German chamomile [*Chamomilla recutita* (L.) Rauschert, Compositae]. Contact Dermatitis 2010;62:338-342

75 Korffmacher H, Hartwig R, Matthes U, Dirschka T, Albassamt A, Weindorf N, Altmeyer P. Contact allergy to 8-methoxypsoralen. Contact Dermatitis 1994;30:283-285

76 Malten KE, van Ketel WG, Nater JP, Liem DH. Reactions in selected patients to 22 fragrance materials. Contact Dermatitis 1984;11:1-10

77 Wenk KS, Ehrlich AE. Fragrance series testing in eyelid dermatitis. Dermatitis 2012;23:22-26

78 Greenspoon J, Ahluwalia R, Juma N, Rosen CF. Allergic and photoallergic contact dermatitis: A 10-year experience. Dermatitis 2013;24:29-32

79 Mitchell JC, Calnan CD, Clendenning WE, Cronin E, Hjorth N, Magnusson B, et al. Patch testing with some components of balsam of Peru. Contact Dermatitis 1976;2: 57-58

80 Oiso N, Fukai K, Ishii M. Allergic contact dermatitis due to methyl salicylate in a compress. Contact Dermatitis 2004;51:34-35

81 de Groot AC, Coenraads PJ, Bruynzeel DP, Jagtman BA, van Ginkel CJW, Noz K, van der Valk PGM, et al. Routine patch testing with fragrance chemicals in The Netherlands. Contact Dermatitis 2000;42:184-185

82 Santucci B, Cristaudo A, Cannistraci C, Picardo M. Contact dermatitis to fragrances. Contact Dermatitis 1987;16:93-95

83 Hayakawa R, Matsunaga K, Arima Y. Depigmented contact dermatitis due to incense. Contact Dermatitis 1987;16:272-274

84 Hayakawa R, Matsunaga K, Arima Y. Airborne pigmented contact dermatitis due to musk ambrette in incense. Contact Dermatitis 1987;16:96-98

85 Dooms-Goossens A, Degreef H, Holvoet C, Maertens M. Turpentine-induced hypersensitivity to peppermint oil. Contact Dermatitis 1977;3:304-308

86 Sanchez-Politta S, Campanelli A, Pashe-Koo F, Saurat JH, Piletta P. Allergic contact dermatitis to phenylacetaldehyde: a forgotten allergen? Contact Dermatitis 2007;56:171-172

87 Dharmagunawardena B, Takwale A, Sanders KJ, Cannan S, Roger A, Ilchyshyn A. Gas chromatography: an investigative tool in multiple allergies to essential oils. Contact Dermatitis 2002;47:288-292

88 Aalto-Korte K, Välimaa J, Henriks-Eckerman M-L, Jolanki R. Allergic contact dermatitis from salicyl alcohol and salicylaldehyde in aspen bark (*Populus tremula*). Contact Dermatitis 2005;52:93-95

89 Goossens A, Merckx L. Allergic contact dermatitis from farnesol in a deodorant. Contact Dermatitis 1997;37:179-180

90 Hayakawa R, Matsunaga K, Arima Y. Depigmented contact dermatitis due to incense. Contact Dermatitis 1987;16:272-274

91 Utsumi M, Sugai T, Shoji A, Watanabe K, Asoh S, Hashimoto Y. Incidence of positive reactions to sandalwood oil and its related fragrance materials in patch tests and a case of contact allergy to natural and synthetic sandalwood oil in a museum worker. Skin Res 1992;34 (Suppl.14):209-213

92 Sugai T. Group study IV – farnesol and lily aldehyde. Environ Dermatol 1994;1:213-214

93 Lippert U, Walter A, Hausen BM, Fuchs Th. Increasing incidence of contact dermatitis to tea tree oil. J Allergy Clin Immunol 2000;105;S43 (abstract 127)

94 Cachao P, Menezes Brandao F, Carmo M, Frazao S, Silva M. Allergy to oil of turpentine in Portugal. Contact Dermatitis 1986;14:205-208

95 Lorenzi S, Placucci F, Vincenzi C, Bardazzi F, Tosti A. Allergic contact dermatitis due to thymol. Contact Dermatitis 1995;33:439-440

96 Nakayama H. Fragrance hypersensitivity and its control. In: Frosch PJ, Dooms-Goossens A, Lachapelle J-M, Rycroft RJG, Scheper RJ, Eds. Current topics in contact dermatitis. Heidelberg: Springer Verlag, 1989:83-91

97 Isaksson M, Inerot A, Lidén C, Lindberg M, Matura M, Möller H, et al. Multicentre patch testing with fragrance mix II and hydroxyisohexyl 3-cyclohexene carboxaldehyde by the Swedish Contact Dermatitis Research Group. Contact Dermatitis 2014;70:187-189

98 Uter W, Geier J, Schnuch A, Gefeller O. Risk factors associated with sensitization to hydroxyisohexyl 3-cyclohexene carboxaldehyde. Contact Dermatitis 2013;69:72-77

99 Heisterberg MV, Laurberg G, Veien NK, Menné T, Avnstorp C, Kaaber K, et al. Prevalence of allergic contact dermatitis caused by hydroxyisohexyl 3-cyclohexene carboxaldehyde has not changed in Denmark. Contact Dermatitis 2012;67:49-51

100 Saito F, Oka K. Allergic contact dermatitis due to peppermint oil. Skin Res 1990;32:161-167

101 Chowdhury MMU, Statham BN. Allergic contact dermatitis from dibutyl phthalate and benzalkonium chloride in Timodine® cream. Contact Dermatitis 2002;46:57

102 Oliwiecki S, Beck MH, Chalmers RJ. Contact dermatitis from spectacle frames and hearing aid containing diethyl phthalate. Contact Dermatitis 1991;25:264-265

103 Capon F, Camble MP, Bernardeau K, Kalis B. Occupational contact dermatitis caused by computer mice. Contact Dermatitis 1996;35:57-58

104 Walker SL, Smith HR, Rycroft RJG, Broome C. Occupational contact dermatitis from headphones containing diethylhexyl phthalate. Contact Dermatitis 2000;42:164

105 Heidenheim M, Jemec GBE. Occupational allergic contact dermatitis from vitamin A acetate. Contact Dermatitis 1995;33:439

Chapter 5 CHEMICAL COMPOSITION OF AND CONTACT ALLERGY TO ESSENTIAL OILS

Chapter 5.0 INTRODUCTION TO THE OIL CHAPTERS

In this chapter, literature data on contact allergy to and chemical composition of essential oils are presented. There are 91 subchapters of individual essential oils and 2 of an absolute (jasmine absolute); these were selected on the sole criterion that they have caused contact allergy. For some oils, only one or two such reports are available. For others, however, there is a considerable amount of literature on contact allergy and allergic contact dermatitis, e.g., in the case of tea tree oil, ylang-ylang oil, lavender oil, peppermint oil, jasmine absolute, geranium oil, rose oil, turpentine oil and sandalwood oil. The relevant literature on contact allergy to/allergic contact dermatitis from any essential oil is discussed in its individual oil chapter. General aspects (e.g., frequency of contact allergy to essential oils, relevance of observed positive patch test reactions, clinical picture of allergic contact dermatitis, products responsible for allergic reactions, co-reactivity to other oils and products, the allergens in essential oils, and diagnostic procedures) are discussed in Chapter 3. A complete alphabetical list of the oils with their common names, botanical names of the source plant species, part of the plant used and ISO standards is given in Chapter 1.

All subchapters, which have the commonly used oil name as title, have a standardized format and present the following sections.

DEFINITION

Here, a definition of the oil is given, including its common name, ISO name (see below), the source species' botanical name and the plant part(s) used for obtaining the essential oil.

INCI NOMENCLATURE

This section provides the definition or description of the oils as provided in CosIng, the European Commission database with information on cosmetic substances and ingredients (http://ec.europa.eu/consumers/cosmetics/cosing/), the names used in the INCI (International Nomenclature Cosmetic Ingredient) systems of the European Union (CosIng) and of the USA (http://online.personalcarecouncil.org/jsp/Home.jsp; paid subscription only), their CAS (Chemical Abstract Service) number(s) (SciFinder, paid subscription only [www.cas.org]; CAS Registry Number is a Registered Trademark of the American Chemical Society; permission has been granted to use the CAS registry numbers) and their EINECS number (European Inventory of Existing Chemical Substances; http://echa.europa.eu/information-on-chemicals/ec-inventory). It should be appreciated that the CosIng database contains a considerable number of mistakes, e.g., the wrong botanical names or CAS numbers.

ISO (INTERNATIONAL ORGANIZATION FOR STANDARDIZATION) STANDARD

This section provides the number of the essential oil's ISO standard (if available), the ISO name of the oil, botanical origin, plant part used and the minimum and maximum acceptable concentrations of the main oil ingredients. We have found some mistakes in these standards, notably the wrong botanical names or aberrant plant parts used. The copyright holder (ISO, Geneva, Switzerland; www.iso.org) has given us permission to reproduce their data.

THE PLANT, THE OIL AND THEIR USES

This section provides general information on the oil's source plant, its origin, cultivation, what the plant is used for and the applications of the essential oil. Many of the plants can be eaten or used as a condiment or spice. Quite often, they are used as medicinal plants, usually in traditional or folk medicine, for a variety of diseases and ailments. A range of pharmacological activities is often attributed to plants or plant parts. The essential oils usually have similar applications, and many are used in foods and drinks, perfumes, cosmetics, topical pharmaceuticals or in other applications such as household products, incense and cigarettes. Virtually all essential oils are used in aromatherapy, which has been defined as 'The therapeutic application of essential oils and aromatic plant extracts in a holistic context, to maintain or improve physical, emotional and mental well-being' (1) or 'the therapeutic use of essential oils' (2). We often give some details of the claimed pharmacological properties and reported therapeutic indications. However, it should be realized that proof of health promoting properties in humans is, according to current standards, virtually always lacking. We wish to emphasize that, by mentioning these data, we do *not* support the various claims made, indications given and uses as described.

CHEMICAL COMPOSITION

This is the main part of the oil chapters, where literature data on the chemical composition of essential oils (both laboratory prepared and commercial) are presented.

Data selection

We have included articles only when oils were analyzed which conform to our definition of 'essential oils' (see Chapter 2): commercial essential oils, laboratory-produced oils obtained by hydrodistillation, steam-distillation, or microwave-assisted hydrodistillation and – in the case of *Citrus* oils – by cold pressing. Oils obtained by simultaneous distillation and extraction, by extraction with solvents or by supercritical fluid extraction (which are often incorrectly termed 'essential oils') were excluded, with the exception of jasmine absolutes. We can, however, not be absolutely certain that some data cited in other publications were not from essential oils sensu stricto.

Data were collected and processed by one of us (ACdG). Most were acquired online through the Library of the University of Groningen, the Netherlands: PubMed (US National Library of Medicine National Institutes of Health), the databases of ScienceDirect (Elsevier), EBSCOhost, ACS Publications (American Chemical Society), Taylor and Francis Online (including the very important journals *Journal of Essential Oil Research* and *Journal of Essential Oil Bearing Plants*), Wiley Online Library, Springer Link, and the online available issues of *Perfumer and Flavorist* (back to November 2008). Other important sources were the three most recent books of Brian M. Lawrence's famous articles 'Progress in essential oils' as reprinted from *Perfumer and Flavorist* (3-5). They contain a wealth of information, also from journals that are difficult to access (his older books are out of print and are very hard to acquire). The literature lists of relevant articles were searched for other useful publications and sometimes obtained from or ordered by the University library, if not available online, including quite a few 'Progress in Essential Oil' articles published in earlier issues of *Perfumer and Flavorist*. Finally the internet was searched for relevant data (most important search terms: 'name of essential oil' chemical composition), which often yielded additional articles, e.g., from open access journals not cited in PubMed. The depth of the search depended on the amount of available data: we tried to obtain all we could find for oils where few analytical data were available, but have not searched exhaustively in the case of oils where much published analytical data are available. Nevertheless, for most oils, we believe we present the great majority (>80-90%) of (more recent) data published in English language scientific literature.

We have found that many analytical studies present data of sub-optimal or even poor quality. In many articles, experimental data were insufficiently described. Quite often, retention times and indices were not provided. Sometimes, analytical methods were inadequate, e.g., the identification of chemicals was based only on retention times. Usually, only one library of mass spectra (mostly NIST) was employed; this increases the risk of misidentification, which can be avoided (or decreased) by also consulting other libraries such as MassFinder, which contains a larger number of spectra for chemicals found in essential oils. In a number of cases, wrong identifications were made on the basis of elution order. In only a few cases, triplicate testing for reliable quantifications had been performed. Rarely, explanations were given for the presence of chemicals which should not be part of essential oils, for example, solvents used for collection of the oil after distillation in a Clevenger apparatus, or synthetic chemicals.

In some studies, names for chemicals were used that we could not find in any chemical database or with the aid of any search engine, and some were probably or certainly wrong. We have chosen *not* to exclude these chemicals from presentation in the tables. The same goes for compounds, which are synthetic and therefore should not be present in essential oils. Obviously, their 'presence' may have been the result of a misidentification by the investigator. However, they can also have entered the oil as the result of adulteration (up to 2004 large amounts of phthalates were sometimes added), contamination (e.g., phthalates from plastic containers, phthalates from disinfectants containing alcohol denatured with diethyl phthalate) or be impurities from the production method, and have been correctly identified. Finally, the possibility that a chemical which is known as a synthetic compound will be found in nature one day, e.g., in an essential oil, although very unlikely, cannot be excluded. Therefore, we have included these chemicals in the data presentation. In Chapter 6 (but mostly not in the individual oil chapters), they are indicated as 'Chemicals which have not been found in nature up to now' and are shown here in Table 5.0.1.

Presentation of analytical data

The heart of the section 'Chemical composition' is a table (usually Table 2) presenting an alphabetical list of chemicals which have been identified in published analytical studies in the essential oil under discussion. For each chemical, the concentrations in which it has been found is given (relative percentage of peak areas in GC/MS; one decimal for all concentrations >0.09%) and in which publications. The table has several columns. Column A always presents unpublished analytical data from one of

Table 5.0.1 Chemicals identified in essential oils which have not been found in nature up to now[a]

Benzodiazepine
5-Benzodiazepine
Bis(2-ethylhexyl)phthalate
Butylcyclohexyl phthalate
Cyclamen aldehyde
Dehydrolinalyl acetate
Dibutyl phthalate
Dichloroacetic acid, 1-adamantylmethyl ester
Diethyl phthalate
Dihydrolinalyl acetate
Dihydromyrcenyl acetate
Dimethyl-*o*-phthalate
Ftalate
Heptafluorobutanoic acid, 2-(1-adamantyl) ethyl ester
α-Hexylcinnamaldehyde
Hydroxycitronellal
Hydroxycitronellol
Ibuprofen
Lilial®
Lyral®
Methyl ethyl phthalate
α-Methylionone
6-Methyl-γ-ionone
6-Methyl-γ-(*E*)-ionone
Musk ambrette
(*E*)-9-Octadecenoic acid, trimethylsilyl ester
7,di-*n*-Octyl phthalate
Phthalate
Phthalic acid
Retinal (= Vitamin A aldehyde)
9-*cis*-Retinal
Retinyl acetate
β-Terpinene
Testosteron (not in flora)
Tetrahydrolinalyl acetate
Vitamin A aldehyde (=Retinal)

[a] we do not pretend this list to be exhaustive

us (Erich Schmidt; see 'Analytical data of commercial oils' below). Then there is a (variable) number of other columns (e.g., B, C, D, E), in which per column all analytical data from one particular study are presented. These are usually the studies with the largest number of ingredients found and/or with the largest number of oil samples analyzed; both commercial oils (which are a small minority) and laboratory-produced oil samples (usually oils hydrodistilled with a Clevenger-type apparatus) qualify.

For a few oils, there is so little published analytical material (that we could find and obtain) that we could show *all* data in this table: cedarwood oil Texas, clove stem oil, elemi oil, guaiacwood oil and neem oil. For the others, showing full analytical data is impossible: for rosemary oils, for example, we show data from over 100 publications.

To be able to show the most important data material (chemicals, concentrations), a wider right column has been created (usually E, F or G), in which data of all publications not shown in the other columns are summarized. There, concentrations for each chemical have a letter (a-z) or a letter plus a number (e.g., y1, z5) attached in superscript. In the legend below the table, these symbols refer to the source study. In most cases, information is also provided on the number of oils investigated, the production mode (commercial, laboratory produced, hydrodistilled or steam-distilled), the plant (cultivated, wild, cultivar, season of harvesting etc.) and the country where the oil(s) was/were produced.

Most data on chemicals found in literature could all be included in this column; in this case the row of the column is not completely filled. For many others, however, there are so much data that they cannot all be shown in the right column. There, we show the *highest* concentrations found in any analytical study. In these cases, the row in the right column is full (sometimes two rows for chemicals with very high concentrations). Thus, it should be realized that such data are not representative of the general composition, as we have selected only the highest concentrations.

Nomenclature

In various studies, chemicals were quite often indicated with different names (common name, chemical name, IUPAC name). In such cases, we have chosen a 'preferred' name to show in the tables. Chapter 6 presents an alphabetical list of all chemicals found in the essential oils with their preferred names; synonyms are included and refer to the preferred name.

Further information provided in the section 'Chemical composition'

This section standard also provides the following information:

- A physical and olfactory description of the oil, its yield (in percentage of biomass) and the main producing countries
- The total number of chemicals identified in the essential oils from various origins and the percentage of these chemicals which have been found in a single study only
- The most important chemicals found in the essential oil (from all literature data) with their maximum concentrations; their details are also shown in a separate table. We realize that these data are heavily influenced by the very heterogeneous results of analyses performed in scientific studies; therefore, we have *also* summarized the ten most important chemicals found in the commercial essential oils analyzed by the second author with minimum and maximum concentrations found
- Chemicals which are known ingredients of the essential oil discussed which were found in unusually high amounts (concentrations are mentioned)
- Chemicals which are unusual or rare constituents of the oil, or have not previously been identified in the essential oil, and which were found in a high concentration in one or two studies
- The ten most important chemicals found in the commercial essential oils analyzed by Erich Schmidt with concentration ranges
- Published information on (possible) chemotypes of the essential oils/source plants

Analytical data of commercial essential oils

In this book, analytical data from one of us (Erich Schmidt) are presented for the first time. Between 1998 and 2014, he analyzed 6,400 samples of the essential oils discussed here. The number of analyses per oil varied from 0 (neem oil, cassia leaf oil) to 422 (sweet orange oil); numbers for each oil are shown in Table 5.0.2. All analytical results (chemicals identified, range of concentrations) can be found in columns A of the main tables of Chapters 5.1-5.93. These results have not previously been published and represent by far the most extensive set of essential oils analyses ever reported in scientific literature. More detailed information can be found in Chapter 1.

Overview of some results presented in Chapters 5.1-5.93 and interpretation of data

Number of chemicals in individual oils

The (approximate) number of chemicals identified in specific essential oils varies considerably (Table 5.0.2). On the low end of the spectrum (turpentine oils and cardamom oil excluded, as we did not perform a literature search on them) are guaiacwood oil (25 chemicals identified), clove stem oil (n=35), cedarwood oil Texas (n=45), elemi oil (n=45), cedarwood oil Virginia (n=55), cedarwood oil Himalaya (n=60), rosewood oil (n=60) and neem oil (n=65). For most of these, this can be explained by the small number of published analytical reports (n=2-5). In the majority, the number of identified components ranges from 100 to 250. Thirteen oils had 250-300 chemical identifications, and ten ranged from 300 to 400. Five oils scored 400-500 identified chemicals: basil oil, laurel leaf oil, lavender oil, rose oil and vetiver oil. At the high end of the spectrum, finally, in geranium oil some 500 chemicals have been identified and 505 in rosemary essential oils.

Chemicals found in one study only

Many chemicals found in an essential oil were identified in one study only; percentages range from 22 to 79. Low percentages (i.e., congruent results of various analyses) are rare: cananga oil 22%, elemi oil 30%, ravensara oil 39%. In the case of cananga oil, the explanation is

Table 5.0.2 Number of commercial oils investigated (A), number of components identified in individual oils (B) and percentage of components found in one study only (C)

Essential oil	A	B	C
Angelica fruit oil	11	120	57%
Angelica root oil	31	165	40%
Aniseed oil	81	120	47%
Basil oil, sweet	47	435	53%
Bay oil	33	110	51%
Bergamot oil	103	250	49%
Black cumin oil	13	340	62%
Black pepper oil	46	305	58%
Cajeput oil	51	130	51%
Calamus oil	14	275	47%
Cananga oil	25	100	22%
Cardamom oil	101	28[a]	NK
Carrot seed oil	41	315	60%
Cassia bark oil	38	245	62%
Cassia leaf oil	0	115	69%
Cedarwood oil, Atlas	24	135	53%
Cedarwood oil, China	21	135	58%
Cedarwood oil, Himalaya	8	60	60%
Cedarwood oil, Texas	119	45	43%
Cedarwood oil, Virginia	36	55	54%
Chamomile oil, German	85	280	56%
Chamomile oil, Roman	22	165	58%
Cinnamon bark oil, Sri Lanka	43	160	46%
Cinnamon leaf oil, Sri Lanka	30	160	52%
Citronella oil, Java	132	165	53%
Citronella oil, Sri Lanka	29	145	52%
Clary sage oil	34	295	59%
Clove bud oil	31	200	67%
Clove leaf oil	201	110	65%
Clove stem oil	29	35	73%
Coriander fruit oil	38	200	48%
Costus root oil	6	135	59%
Cypress oil	33	205	57%
Dwarf pine oil	283	170	57%
Elemi oil	39	45	30%
Eucalyptus citriodora oil	57	220	60%
Eucalyptus globulus oil	185	250	58%
Galbanum resin oil	21	225	75%
Geranium oil	97	500	60%
Ginger oil	41	295	51%
Grapefruit oil	122	210	NK[b]
Guaiacwood oil	27	25	52%
Hyssop oil	26	285	52%
Jasminum grandiflorum abs.	41	220	68%
Jasminum sambac absolute	11	270	61%
Juniper berry oil	395	295	45%
Laurel leaf oil	23	425	54%
Lavandin abrial oil	110	88	45%
Lavandin grosso oil	148	100	44%
Lavandin oil	26	180	61%
Lavender oil	374	450	64%
Lemon oil	178	245	NK[b]
Lemongrass oil, East Indian	44	175	52%
Lemongrass oil, West Indian	32	245	57%
Litsea cubeba oil	101	170	61%
Lovage oil	17	95	52%
Mandarin oil	98	255	NK[b]
Marjoram oil (sweet)	49	240	55%
Melissa oil (lemon balm oil)	53	310	49%
Myrrh oil	46	110	69%
Neem oil	0	65	NK[c]
Neroli oil	79	190	50%
Niaouli oil	39	150	46%
Nutmeg oil	51	120	NK[b]
Olibanum (frankincense) oil	28	245	58%
Orange oil, bitter	72	215	NK[b]
Orange oil, sweet	422	335	NK[b]
Palmarosa oil	34	155	49%
Patchouli oil	52	210	66%
Peppermint oil	157	335	59%
Petitgrain bigarade oil	47	157	45%
Pine needle oil	112	255	56%
Ravensara oil	41	95	39%
Rosemary oil	108	505	53%
Rose oil	51	440	56%
Rosewood oil	36	60	42%
Sage oil, Dalmatian	55	310	47%
Sage oil, Spanish	42	120	41%
Sandalwood oil, East India	39	125	69%
Sandalwood oil, Australia	23	90	70%
Sandalwood, New Caledonia	39	90	73%
Silver fir oil	16	110	42%
Spearmint oil	71	250	45%
Spike lavender oil	24	395	63%
Star anise oil	41	160	54%
Tangerine oil	28	125	46%
Tea tree oil	97	220	55%
Thuja oil	44	120	42%
Thyme oil	25	325	50%
Thyme oil, Spanish	38	170	47%
Turpentine oil, Iberian type	47	31[a]	NK
Turpentine oil, Chinese type	42	37[a]	NK
Valerian oil	11	330	50%
Vetiver oil	51	445	55%
Ylang-ylang oil extra	51	190	46%
first	12	145	55%
second	42	120	52%
third	22	170	58%
Zdravetz oil	8	275	79%

A number of commercial oils analyzed by Erich Schmidt in the period 1998-2014

B approximate number of chemicals identified in essential oils of various origins

C approximate percentage of chemicals found in one study only

NK not known

[a] low number, because no literature review has been performed

[b] the percentage of chemicals found in one study only cannot be calculated as a result of the data collection method

[c] only one major analytical investigation published

simple: there were two (different?) studies from the same authors with largely the same results, which means that most chemicals were already found in two studies. The same goes for ravensara oil: two reports from the same authors and also from the same source material.

In >80% of the oils, between 40 and 65% of the chemicals are identified only in one study. In 11 oils, this applied to over 2/3 of all chemicals. In some of these cases, a low number of analytical studies may be the explanation (clove stem oil 3 studies, zdravetz oil 4, sandalwood oil New Caledonia 5, cassia leaf oil 7). However, clove bud oil has 40 analytical publications and patchouli oil more than 50, but still 67% resp. 66% of the chemicals in these oils were found in one study only! In the majority of cases, the singles are found in lab-hydrodistilled oils from wild plants or sometimes from material purchased at a local market. Possible explanations include genetic diversity of the source plant material from adaptation to local circumstances, the use of different plant species for the same oil (e.g., geranium oil, rose oil, myrrh oil, rosewood oil, tea tree oil, turpentine oil), the use of different cultivars, botanical misinterpretation or mistakes made in analysis. In some studies, only certain fractions of the oil were investigated, which yields chemicals which have such low concentrations that they go unnoticed when the entire oil is analyzed (and thus presented in one study only). Factors affecting the composition of essential oils are discussed in Chapter 2.

Atypical compositions

Atypical compositions have been published for most oils. Some are extremely atypical, which might indicate a botanical misidentification, but genetic variations can often not be excluded. Also, many studies report well-known constituents in atypically high (or low) concentrations and some present chemicals which are rare or even previously absent in the essential oils, in (very) high concentrations. These findings can either be correct or wrong, which is usually difficult to assess on the basis of the data presented. Factors affecting the composition of essential oils are discussed in Chapter 2.

Contact allergy/allergic contact dermatitis

This section provides a detailed review of the literature on contact allergy to the essential oil, starting with the subsection General (a surveying summary), followed by (if applicable) Testing in groups of patients, Case reports, Positive patch test reactions and Allergens in essential oils. General aspects of contact allergy to essential oils are presented in Chapter 3.

Literature

In this section, full bibliographical data of all reviewed articles are given. In some references of BM Lawrence's articles 'Progress in Essential Oils' in *Perfumer and Flavorist*, the number of the last page is missing ('last page unknown'). We *did* read those articles, though not in the journal, but in the Essential Oil books (3-5). The articles have been reprinted there, with only their first page number given; we have not been able to find a full bibliographic data source for these articles.

LITERATURE

1 Rhind JP. Essential oils. A handbook for aromatherapy practice, 2nd Edition. London: Singing Dragon, 2012

2 Lawless J. The encyclopedia of essential oils, 2nd Edition. London: Harper Thorsons, 2014

3 Lawrence BM. Essential oils 2001-2004. Carol Stream, USA: Allured Publishing Corporation, 2006

4 Lawrence BM. Essential oils 2005-2007. Carol Stream, USA: Allured Publishing Corporation, 2008

5 Lawrence BM. Essential oils 2008-2011. Carol Stream, USA: Allured Publishing Corporation, 2012

Chapter 5.1 ANGELICA FRUIT OIL

There are two forms of Angelica essential oils, fruit and root oil. In this chapter, the fruit oil is discussed. Angelica root oil is presented in Chapter 5.2.

DEFINITION

Angelica fruit oil is the essential oil obtained from the fruit of the angelica (wild parsnip), *Angelica archangelica* L. (synonyms: *Angelica officinalis* Moench, *Archangelica officinalis* (Moench) Hoffm.).

INCI NOMENCLATURE

Description/definition: Angelica archangelica seed oil is the volatile oil obtained from the seeds of the holy ghost, *Angelica archangelica* L., Umbelliferae (Apiaceae)

INCI name EU & USA: Angelica archangelica seed oil

CAS registry number(s): 8015-64-3; 84775-41-7
EINECS number(s): 283-871-1

The fruits and seeds are often considered as synonymous, but the seeds are contained within the fruits. The seed oil mentioned in INCI is an essential oil, not a fixed oil, and probably synonymous with the fruit oil.

ISO (INTERNATIONAL ORGANIZATION FOR STANDARDIZATION) STANDARD

There is currently no ISO standard for Angelica fruit oil.

THE PLANT, THE OIL, AND THEIR USES

For general information on *Angelica archangelica* L. see under Angelica root oil. Commercial angelica root and fruit (=seed) oils are mostly obtained from cultivated *Angelica archangelica* L. ssp. *angelica* var. *sativa* (8).

CHEMICAL COMPOSITION

Angelica fruit oil is a clear, mobile, pale yellow to amber liquid which has a fresh, pungent, terpenic odor. The yield of essential oil from the fruits of *Angelica archangelica* L. generally varies from 0.8 to 1.2%. The main producing countries of this oil are France, the Netherlands, Hungary and USA.

Literature data (up to November 1, 2014) on the chemical composition of angelica fruit oils and unpublished analytical data from one of us (E.S.) are shown in Table 5.1.1 in alphabetical order. In angelica fruit oils from various origins, over 120 chemicals have been identified. About 57% of these were found in a single reviewed publication only. The major compounds found in angelica fruit oils from different sources are shown in Table 5.1.2. They include (highest concentrations in any study given): β-phellandrene (76.0%), α-pinene (41.4%), β-pinene (7.8%), α-phellandrene (7.4%), myrcene (6.3%) and limonene (2.9%). Well-known ingredients of angelica fruit oils that were present in high concentrations in one study only were sabinene (20.4%) and bicyclogermacrene (10.1%).

Commercial oils

The ten chemicals that had the highest maximum concentrations in 11 commercial angelica fruit essential oil samples (concentration ranges provided) are the following: β-phellandrene (52.1-76.0%), α-pinene (2.3-13.3%), myrcene (0.6-5.0%), α-phellandrene (0.7-3.7%), limonene (2.3-2.9%), (*E*)-β-ocimene (0.5-1.8%), bicyclogermacrene (0.4-1.5%), camphene (0.1-1.2%), cryptone (0.01-1.2%) and α-humulene (0.5-1.1%) (Erich Schmidt, unpublished analytical data).

CONTACT ALLERGY/ALLERGIC CONTACT DERMATITIS

Angelica oil (unspecified)

General

Contact allergy to/allergic contact dermatitis from angelica oil (plant part unspecified) has been reported in two publications only.

Testing in groups of patients

Two hundred dermatitis patients from Poland were tested with angelica oil 2% in petrolatum and two (1%) reacted; relevance data were not provided (12). In a group of 51 patients allergic to *Myroxylon pereirae* resin (balsam of Peru) and/or turpentine and/or wood tar and/or colophony and tested with angelica oil 2% in petrolatum, three (5.9%) had a positive patch test; relevance data were not provided (12).

Case report

A female aromatherapist developed occupational contact dermatitis of the hands from contact allergy to angelica oil; she also reacted to ylang-ylang oil and geraniol, which were also used at her work (11).

Angelica fruit oil

General

Contact allergy to/possible allergic contact dermatitis from angelica fruit oil has been reported in one publication only. A false-positive patch test reaction due to the excited skin syndrome cannot be excluded. In the same case report, α-pinene may have been an allergen in angelica fruit.

Case reports

One case of non-occupational contact dermatitis in an aromatherapist with allergies to multiple essential oils used at work, including angelica seed oil. The patient also reacted to geraniol, linalool, linalyl acetate, α-pinene, the fragrance mix and various other fragrance materials. α-Pinene, linalool, and geraniol were demonstrated by GC-MS in angelica seed oil (13); α-pinene may be an important constituent in angelica fruit oils and has been found in concentrations of up to 13.3% in commercial angelica fruit oils (Table 5.1.1, column A).

Table 5.1.1 Constituents identified in angelica fruit oils

Constituent	CAS	Percentage and range						
		A	B (2)	C (1)	D (7)	E (3)	F (4)	G
(*E*)-Anethole	4180-23-8					0.7		
Angelic acid	565-63-9	0.01-0.1						
Artemisia ketone	546-49-6	0.07-0.08						
Benzyl isovalerate	103-38-8		0-0.1			0.1		
Bergaptene	484-20-8		tr-0.4					
Bicycloelemene	32531-56-9							0.8-3.2[c]
Bicyclogermacrene	24703-35-3	0.4-1.5			0.4	1.5	2.3	3.0-10.1[c]
β-Bisabolene	495-61-4		0.6-1.6		0.3[a]			
α-Bisabolol	515-69-5		tr-0.5					
epi-α-Bisabolol	78148-59-1		0-0.2					
(6R,7R)-Bisabolone	72441-71-5		tr-0.2					
Borneol	507-70-0			0.1				
Bornyl acetate	76-49-3	0.0-0.1	0.1-0.2	0.06		<0.5		
β-Bourbonene	5208-59-3		0.1-0.4	tr	0.1	<0.5	0.9	
n-Butyl angelate	7785-64-0	0.0-0.07			0.06			
α-Cadinene	24406-05-1		0-0.1				2.1	
γ-Cadinene	39029-41-9		tr-0.2			0.5		
δ-Cadinene	483-76-1	0.08-0.6	tr-1.3	tr	0.2	0.6		
α-Cadinol	481-34-5		0-0.1				0.5	
Camphene	79-92-5	0.1-1.2	0.1-0.5	0.3	0.4	0.1	0.4	
Camphor	76-22-2		tr					
δ3-Carene	13466-78-9	0.06-0.1	tr-0.5	0.2	0.07	<0.5	7.5	
β-Caryophyllene	87-44-5	0.05-0.08	0.1-0.4	0.08	0.07	<0.5		
Caryophyllene oxide	1139-30-6		tr-0.2	tr				
α-Copaene	3856-25-5	0.2-0.8	tr-0.3	0.2	0.8			3.3[b]; 0.3-0.6[c]
β-Copaene	18252-44-3			0.06			0.3	
Cryptone	500-02-7	0.01-1.2	0.2-0.4	0.1		1.1		2.6[b]
β-Cubebene	13744-15-5				0.03			
10-epi-Cubebol	176589-53-0		0-0.1					
Cuminaldehyde	122-03-2						0.1	
ar-Curcumene	644-30-4		0-0.7		0.1			0-0.9[c]
γ-Curcumene	28976-68-3		0-3.2					
p-Cymene	99-87-6	0.06-1.0	tr-0.1	0.6	0.5	0.8		
p-Cymen-7-ol	536-60-7		0-tr					
p-Cymen-8-ol	1197-01-9		0-tr					
β-Elemene	33880-83-0		0.1-0.3		0.1	3.4		
γ-Elemene	29873-99-2		0.6-1.4		0.08			0.2-2.4[c]
δ-Elemene	20307-84-0		tr-0.2					
cis-β-Elemenone	32663-57-3		0-0.1					
Elemol (α-)	639-99-6		0.2-1.3					
(*E*)-β-Farnesene	18794-84-8		0.2-0.4	tr				
Farnesol	4602-84-0					<0.5		
(*E*,*Z*)-Farnesol	3879-60-5		0.1					
(*E*,*E*)-Farnesyl acetate	4128-17-0		0-tr					
Germacrene B	15423-57-1		0.1	0.3	0.7		0.6	0.1-1.3[c]
Germacrene D	23986-74-5	0.2-0.7	0.2-3.0		0.7	0.3	2.6	
Heptadecanolide	5637-97-8			tr				
Heptanal	111-71-7					<0.5		
(*Z*)-2-Hexenyl iso-valerate			0-0.1					
Hexyl isovalerate	10032-13-0		tr-0.1			<0.5		
α-Humulene	6753-98-6	0.5-1.1	1.0-3.4	0.6	1.1	0.8	1.5	
Humulene epoxide II	19888-34-7		0-0.5					
Isoamyl benzyl ether	122-73-6		0-0.6					
Isoamyl isovalerate	659-70-1	0.08-0.3	0.1-0.9			0.3		
Isoamyl 2-methylbuty-rate	27625-35-0	0.08-0.1	tr-0.5					
Isobergaptene	482-48-4		tr-0.2					
Isobutyl isovalerate	589-59-3	0.09-0.7						
Isopropyl angelate	61692-76-0	0.0-0.5						
Isopropyl isovalerate	32665-23-9	0.0-0.6						
Isopropyl 2-methyl- butyrate	66576-71-4	0.02-0.1						
Isopropyl tiglate	1733-25-1	0.0-0.2						
Isoterpinolene	586-63-0			tr			0.3	

Table 5.1.1 Constituents identified in angelica fruit oils (*continued*)

Constituent	CAS	Percentage and range						
		A	B (2)	C (1)	D (7)	E (3)	F (4)	G
Isovaleraldehyde	590-86-3					<0.5		
Limonene	138-86-3	2.3-2.9	2.7	2.3		1.8		0.5-1.7[c]
Linalool	78-70-6			0.3		<0.5		
Linalyl acetate	115-95-7			0.2				
Longicyclene	1137-12-8		0-tr			0.6		
Longifolene (junipene)	475-20-7		0-0.9					
Longipinanol	66141-14-8		0.1-1.6					
α-Longipinene	5989-08-2						0.7	
p-Mentha-1,5-dien-8-ol	1686-20-0		0-0.1					
p-Menth-1-en-7-al	21391-98-0		0-0.1					
p-Menth-2-en-1-ol	619-62-5					<0.5		
cis-*p*-Menth-2-en-1-ol	29803-82-5		0-0.1					
Menthol	89-78-1		0-0.1					
3-Methyl-3-butenyl isovalerate	54410-94-5		0-0.4					
2-Methylbutyl 2-me-thylbutyrate	2445-78-5					0.07		
2-Methylbutyl valerate	55590-83-5				0.09			
Methylcarvacrol	6379-73-3					<0.5		
Methyl hexadecanoate	112-30-0		tr-0.2					
Methyl octadecanoate	112-61-8		tr-0.2					
Methyl thymol	1076-56-9					<0.5		
trans-Muurola-3,5-diene	262352-88-5		0-0.2					
α-Muurolene	10208-80-7		0.1-1.6	0.07	0.3[a]			
γ-Muurolene	30021-74-0		0.2-2.1	0.5				
α-Muurolol	104245-48-9		tr-1.2					
Myrcene	123-35-3	0.6-5.0	2.0-6.3	2.9	2.9	3.2	3.6	0-2.1[c]
(*E*)-Nerolidol	40716-66-3		0-0.1					
(*E*)-β-Ocimene	3779-61-1	0.5-1.8	tr-0.6	0.3	0.5	1.8		
(*Z*)-β-Ocimene	3338-55-4	0.2-0.6	0-0.1	0.2	0.3	0.6	0.6	
3-Octanone	106-68-3						1.5	
Osthole	484-12-8		tr-0.2					
15-Pentadecanolide	106-02-5	0.07-0.3	0.4-1.1	0.2	0.2	0.6		
α-Phellandrene	99-83-2	0.7-3.7	2.6-7.4	3.7	2.7	1.9		2.3[b]; 0-3.4[c]
β-Phellandrene	555-10-2	52.1-76.0	33.6-63.4	74.7	72.1	65.8	49.3	59.4[b]; 0-55.2[c]
2-Phenylethyl 2-methylbutyrate	24817-51-4		0-0.4					
α-Pinene	80-56-8	2.3-13.3	4.2-12.8	6.6	8.8	6.6	15.1	2.9[b]; 14.4-41.4[c]
β-Pinene	127-91-3	0.3-0.8	0.6-3.7	0.6	0.7	0.6	7.8	0.7-1.7[c]
trans-Pinocarvyl acetate	1686-15-3		0-0.7					
Pseudolimonene	499-97-8	0.1-0.6			0.6		2.6	
Sabinene	3387-41-5	0.2-0.7	1.3-20.4	0.4	0.7	0.2		0.3-2.4[c]
cis-Sabinene hydrate	15537-55-0		0-0.3					
trans-Sabinene hydrate	17699-16-0		0-0.2					
trans-Sabinyl acetate	139757-62-3		tr-0.2					
Selina-3,7(11)-diene	6813-21-4		0-0.3					
(*E*)-Sesquilavandulol	104121-84-8		0-0.5					
β-Sesquiphellandrene	20307-83-9		0-0.7		0.2			0-0.7[c]
Spathulenol	6750-60-3		tr-0.3			2.5	0.5	0.3-1.6[c]
α-Terpinene	99-86-5			tr				
γ-Terpinene	99-85-4	0.01-0.02	tr-0.5	tr		<0.5	0.5	
Terpinen-4-ol	562-74-3		0.2-0.6	0.2			0.7	
α-Terpineol	98-55-5		tr					
Terpinolene	586-62-9	0.06-0.09	0.2-0.4	0.09	0.09	<0.5		
Tetradecanal	124-25-4		0-0.3					
α-Thujene	2867-05-2		tr-0.1	0.2		<0.5		
13-Tridecanolide	1725-04-8	0.0-0.3	0.6-1.3	0.3	0.2			
cis-Verbenol	1845-30-3		0-0.2					
trans-Verbenol	1820-09-3		0.2-0.3					
α-Ylangene	14912-44-8		tr-0.2		0.1			
β-Ylangene	20479-06-5		0-0.3					
α-Zingiberene	495-60-3		0-2.4		0.6			0.4-3.6[c]

Table 5.1.1 Constituents identified in angelica fruit oils (*continued*)

A eleven essential oil samples from France, Hungary and Germany, analyzed between 1997 and 2008; lowest and highest concentrations given (E. Schmidt, unpublished data)
B five lab-hydrodistilled seed oils from wild growing *Angelica archangelica* in three habitats in Lithuania; lowest and highest concentrations given (ref. 2); parts of these data had been previously published in ref. 5.
C one laboratory steam-distilled oil from dried angelica seeds (ref. 1)
D one oil of angelica seed (ref. 7)
E two lab-hydrodistilled fruit oils from wild growing and transplanted French *Angelica archangelica* ssp. *archangelica* var. *sativa*; highest concentrations given (ref. 3)
F one lab-distilled oil from wild growing angelica from Siberia (not absolutely certain that it is the correct species) (ref. 4)
G data from other studies (indicated with superscript letters); highest concentrations found in any study reviewed here are given; when two or more oils were investigated, only the highest concentrations are mentioned, unless indicated otherwise

[a] β-bisabolene and α-muurolene combined; [b] five main constituents of the seed oils from Central Station of Seed Production in Bydgoszcz, Poland (ref. 9); [c] three laboratory steam-distilled oils from *A. archangelica* fruits from Iceland; lowest and highest concentrations given (ref. 10)

tr: trace (in column B: <0.1; in column C: <0.06)

Table 5.1.2 Major constituents of angelica fruit oils

Constituent	CAS	Percentage and range						
		A	B (2)	C (1)	D (7)	E (3)	F (4)	G
β-Phellandrene	555-10-2	52.1-76.0	33.6-63.4	74.7	72.1	65.8	49.3	59.4[b]; 0-55.2[c]
α-Pinene	80-56-8	2.3-13.3	4.2-12.8	6.6	8.8	6.6	15.1	2.9[b]; 14.4-41.4[c]
β-Pinene	127-91-3	0.3-0.8	0.6-3.7	0.6	0.7	0.6	7.8	0.7-1.7[c]
α-Phellandrene	99-83-2	0.7-3.7	2.6-7.4	3.7	2.7	1.9		2.3[b]; 0-3.4[c]
Myrcene	123-35-3	0.6-5.0	2.0-6.3	2.9	2.9	3.2	3.6	0-2.1[c]
Limonene	138-86-3	2.3-2.9	2.7	2.3	1.8			0.5-1.7[c]

LEGEND: SEE UNDER TABLE 5.1.1

LITERATURE

1. Lopes D, Strobl H, Kolodziejczyk P. 14-Meth ylpentadecano-15-lactone (Muscolide): A new macrocyclic lactone from the oil of *Angelica archangelica* L. Chem Biodivers 2004;1:1880-1887
2. Nivinskiene O, Butkiene R, Mockute D. The seed (fruit) essential oils of *Angelica archangelica* L. growing wild in Lithuania. J Essent Oil Res 2007;19:477-481
3. Bernard C. Essential oils of three *Angelica* L. species growing in France. Part II: Fruit oils. J Essent Oil Res 2001;13:260-263
4. Shchipitsyna OS, Efremov AA. Composition of ethereal oil isolated from various vegetative parts of *Angelica* from the Siberian region. Russ J Bioorg Chem 2011;37:888-892
5. Nivinskienė O, Butkienė R, Mockutė D. Chemical composition of seed (fruit) essential oils of *Angelica archangelica* L. growing wild in Lithuania. Chemia 2005;16:51-54
6. Lawrence BM. Essential oils 2005-2007. Carol Stream, USA: Allured Publishing Corporation, 2008:64-65
7. Kubeczka K-H, Formacek V. Essential oils analysis by capillary gas chromatography and carbon-13 NMR Spectroscopy, 2nd edition. New York, USA: John Wiley and Sons, 2002:3-9; data cited in ref. 6
8. Lawrence BM. Progress in essential oils. Angelica root and seed oils. Perfum Flavor 1999;24:47-49
9. Wolski T, Najda A, Ludwichuk A. The content and composition of essential oils and fatty acids obtained from the fruits of angelica (*Angelica officinalis* Hoffm.). Herba Polonica 2003;49:151-156
10. Sigurdsson S, Ögmundsdottir HM, Gudbjarnason S. The cytotoxic effect of two chemotypes of essential oils from the fruits of *Angelica archangelica* L. Anticancer Res 2005;25:1877-1880
11. Keane FM, Smith HR, White IR, Rycroft RJG. Occupational allergic contact dermatitis in two aromatherapists. Contact Dermatitis 2000;43:49-51
12. Rudzki E, Grzywa Z, Bruo WS. Sensitivity to 35 essential oils. Contact Dermatitis 1976;2:196-200
13. Dharmagunawardena B, Takwale A, Sanders KJ, Cannan S, Roger A, Ilchyshyn A. Gas chromatography: an investigative tool in multiple allergies to essential oils. Contact Dermatitis 2002;47:288-292

Chapter 5.2 ANGELICA ROOT OIL

There are two forms of Angelica essential oils, fruit and root oil. In this chapter, the root oil is discussed. Angelica fruit oil is presented in Chapter 5.1.

DEFINITION

Angelica root oil is the essential oil obtained from the roots and rhizomes of the angelica (wild parsnip), *Angelica archangelica* L. (synonyms: *Angelica officinalis* Moench, *Archangelica officinalis* (Moench) Hoffm., *Angelica sativa* Mill.).

INCI NOMENCLATURE

Description/definition: Angelica archangelica root oil is the volatile oil obtained from the roots of the plant holy ghost, *Angelica archangelica* L., Umbelliferae (Apiaceae)

INCI name EU & USA: Angelica archangelica root oil

CAS registry number(s): 8015-64-3; 84775-41-7

EINECS number(s): 283-871-1

ISO (INTERNATIONAL ORGANIZATION FOR STANDARDIZATION) STANDARD

There is currently no ISO standard for angelica root oil.

THE PLANT, THE OIL, AND THEIR USES

Angelica archangelica L. is an aromatic, perennial herb that grows up to 2 meters tall. The plant is native to the temperate regions of Asia (Caucasus, Siberia), northern, middle and east Europe, and the Himalayas, and has become widely naturalized in northern temperate regions. The plant is cultivated in Italy, Germany, Finland, Hungary, and several other countries including Korea, India and North America (GRIN Taxonomy for Plants; www.kew.org). Commercial angelica root and fruit oils are mostly obtained from cultivated *Angelica archangelica* L. ssp. *angelica* var. *sativa* (12).

Angelica is used on a large scale in the grocery trade. The roots and fruits of the angelica and their essential oils are popular flavoring agents for confectionary, liqueurs and other beverages such as Bénédictine, Chartreuse, gin and absinthe. *A. archangelica* is believed to possess 'angelic' healing power and has many medicinal applications. This plant has been used in traditional and folk medicine as a remedy for nervous headaches, anxiety, fever, skin rashes, wounds, rheumatism, and toothaches (1,4). *A. archangelica* is employed as an antiseptic, expectorant, emmenagogue (induces or hastens menstruation), and a diuretic. In the Chinese system of medicine, the plant is commonly used for cerebral diseases (1). A leaf extract of the angelica may have a beneficial effect on nocturia in individuals with decreased nocturnal bladder capacity (2).

Essential oils of the fruits (often incorrectly referred to as 'seeds', as the seeds are contained within the fruits) and roots of *Angelica archangelica* are used for healing purposes, as a spice and as a fragrance component in perfumery (3) and cosmetics. These oils are believed to exhibit antispasmodic, stimulant, carminative, diuretic, nervine, tonic and some other activities (6). Angelica root oils are also part of aromatherapy practices (9). The biological activities and medicinal uses of *Angelica archangelica* L. are reviewed in references 1 and 4.

CHEMICAL COMPOSITION

Angelica root oil is, when freshly distilled, a colorless, mobile liquid; with storage, its color changes from yellowish to brownish. The odor is aromatic, spicy with a peppery touch and a typical earthy-rooty character. The yield of essential oil from the roots of *Angelica archangelica* L. generally varies from 0.2 to 0.6% for fresh roots and 0.8 to 1.4% for dried roots. The main producing countries of this oil are Hungary, France, Poland, Lithuania, Germany, Netherlands and India.

Literature data (up to November 1, 2014) on the chemical composition of angelica root oils and unpublished analytical data from one of us (E.S.) are shown in Table 5.2.1 in alphabetical order. In angelica root oils from various origins, over 165 chemicals have been identified. About 40% of these were found in a single reviewed publication only. The major compounds found in angelica root oils from different sources are shown in Table 5.2.2. They include (highest concentrations in any study given) α-pinene (32.2%), β-phellandrene (30.5%), α-phellandrene (22.0%), δ3-carene (17.5%), limonene (16.4%), myrcene (13.1%), sabinene (11.3%) and *p*-cymene (10.6%). Well-known ingredients of angelica root oils that were present in concentrations of 4% or higher in one or two studies were osthole (5.3 and 8.8%), cyclopentadecanolide (14.9%), germacrene D (9.1%), 13-tridecanolide (6.1%), terpinen-4-ol (5.1%), and α-copaen-11-ol (4.5%). Uncommon or rare constituents found in high concentrations in single studies include (*Z*)-β-farnesene (7.1%).

Commercial oils

The ten chemicals that had the highest maximum concentrations in 31 commercial angelica root essential oil samples (concentration ranges provided) are the following: α-pinene (11.4-27.0%), α-phellandrene (4.5-22.0%), β-phellandrene (9.4-18.7%), δ3-carene (6.4-17.5%), limonene (6.4-15%), sabinene (0.6-11.3%), *p*-cymene (1.3-8.4%), (*E*)-ocimene (0-5.9%), myrcene (1.4-5.4%) and (*Z*)-β-ocimene (0.7-4.6%) (Erich Schmidt, unpublished analytical data).

Chemotypes

The composition of Indian angelica oil is quite different from oils produced elsewhere. Its main compounds are α-pinene (>80%) and myrcene (1.2–11.4%). β-Phellandrene (0.2%) and α-phellandrene (<0.1 %) are present in very low concentrations, contrasting to the high concentrations found in oils from other origins (Table 5.2.1); δ3-carene and the ocimenes may be absent (E.S., unpublished analytical data from two Indian samples of angelica oils).

Table 5.2.1 Constituents identified in angelica root oils

Constituent	CAS	Percentage and range					
		A	B (9)	C (11)	D (5)	E (3)	F
(*E*)-Anethole	4180-23-8						+^{f}
Angelicin	523-50-2						+^{a}
Aromadendrene	489-39-4			0-0.7			
γ-Atlantone	532-66-1				0.03		
cis-α-Bergamotene	18252-46-5						0.4^{b}
Bergapten	484-20-8						+^{f}
Bicyclogermacrene	24703-35-3		0.1-0.5	0.1-0.6			2.0^{b}
β-Bisabolene	495-61-4	0.1-1.7	0.3-2.3	0.3-1.3		0.2	+^{f}
Bisabolone			tr-0.4	0-0.5			
Borneol	507-70-0				0.2	tr	0.9^{c}
Bornyl acetate	76-49-3	0.3-3.2	1.8-4.3	2.4-4.2	1.8	0.1	+^{f}; 0.4^{e}; 0.8^{c}
Bornyl isovalerate	76-50-6						+^{f}
β-Bourbonene	5208-59-3						0.9^{b}
Cadina-1,4-diene	29837-12-5		tr-0.5	tr-0.5			
α-Cadinene	24406-05-1						0.8^{b}
γ-Cadinene	39029-41-9		tr-0.6	0-0.4			+^{f}; 0.5^{b}
δ-Cadinene	483-76-1	0.06-0.9	0.2-0.9	0.2-0.9	0.07	0.3	+^{f}; 0.1^{e}; 0.2^{g}; 0.8^{c}; 1.4^{b}
α-Cadinol	481-34-5				0.06		0.9^{b}
δ-Cadinol	19435-97-3				0.04		
Camphene	79-92-5	0.7-1.8	0.7-1.5	0.2-1.5	1.9	0.4	+^{f}; 0.9^{b,e}; 1.5^{g}
δ2-Carene	554-61-0	0.08-0.4			0.2	0.1	0.1^{e}; 0.2^{g}
δ3-Carene	13466-78-9	6.4-17.5	10.6-16.9	3.4-16.0	16.3	5.7	+^{f}; 0.3^{b}; 13.7^{c}; 13.8^{e}; 16.5^{g}
(*E*)-Carveol	1197-07-5						+^{f}
Carvone	99-49-0						+^{f}
Carvyl acetate	97-42-7			0-0.1	0.2		
cis-Carvyl acetate	1205-42-1		0-0.3	0-0.2			
trans-Carvyl acetate	1134-95-8		tr-0.1				
β-Caryophyllene	87-44-5	0.06-0.4	tr-1.2	tr-0.3		0.2	0.2^{g}
γ-Caryophyllene	118-65-0		tr-0.4	0.1-0.7			+^{f}
Caryophyllene oxide	1139-30-6		0.1-0.3	0.2-0.4	0.04		
α-Cedrene	469-61-4						0.7^{b}
β-Cedrene	546-28-1		0.1-0.7	0.1-0.4			0.7^{b}
cis-Chrysanthenyl acetate	67999-48-8		tr-0.4	0.1-0.6			+^{f}
trans-Chrysanthenyl acetate	50764-55-1		tr-0.5	0.1-1.1			+^{f}
α-Copaene	3856-25-5	0.1-1.7	0.1-0.7	0.1-0.6	0.6	0.9	+^{f}; 0.4^{e}; 0.9^{c,g}
β-Copaene	18252-44-3				0.2	0.2	0.2^{g}; 0.3^{b}; 0.6^{c}
Copaene alcohol					0.04		
Copaen-4α-ol (β-)	124753-76-0			tr-0.3			
α-Copaen-8-ol (*cis*-)	58569-25-8		0.1-0.7	0.1-2.5	0.2		
α-Copaen-11-ol	41370-56-3		0.3-1.8	0.3-4.5	tr		+^{f}; 1.2^{c}
Cryptone	500-02-7				0.2		1.1^{e}
α-Cubebene	17699-14-8						+^{f}
β-Cubebene	13744-15-5	0.08-0.3	0.1-0.5	0-0.4			
Cuparene	16982-00-6		0.1-0.4				
α-Cuparene				0.1-0.4	0.03		
Curcumene (*ar*-; α-)	644-30-4						+^{f}
Cyclopentadecanolide	106-02-5	0.06-3.6	1.9-3.6	2.0-14.9	0.9	0.5	+^{f}; +^{d}
m-Cymene	535-77-3						0.1^{e};
o-Cymene	527-84-4	0.03-0.1					
p-Cymene	99-87-6	1.3-8.4	1.5-10.6	0.6-3.9	6.4	5.0	+^{f}; 2.2^{g}; 6.2^{c}; 8.8^{e}
p-Cymenene	1195-32-0	0.1-0.3	0-1.1	0-4.6			0.1^{e}
m-Cymen-8-ol	5208-37-7	0.06-0.3			0.2		+^{f}; 0.2^{g};
p-Cymen-7-ol	536-60-7		0.1-1.0	0.1-0.7			
p-Cymen-8-ol	1197-01-9		tr-1.0	0.1-1.1	0.7		0.2^{e}
β-Elemene	33880-83-0	0.1-1.6	0.1-0.6	0.1-0.6			+^{f}; 0.1^{e}; 0.2^{g}; 3.4^{b}
γ-Elemene	29873-99-2		0.4-1.7	0.6-2.2	0.06		
cis-γ-Elemene							0.9^{b}
δ-Elemene	20307-84-0		tr-0.2	tr-0.2	0.4		
Elemol	639-99-6		0.2-1.6	0.3-2.9	0.05		
4,8-Epoxyterpinolene	4584-23-0						0.1^{e};
α-Eudesmol	473-16-5		0.1-1.0	0.1-1.1			
β-Eudesmol	473-15-4		0.4-2.2	0.4-1.8	0.5		+^{f}

Table 5.2.1 Constituents identified in angelica root oils (*continued*)

Constituent	CAS	Percentage and range					
		A	B (9)	C (11)	D (5)	E (3)	F
γ-Eudesmol	1209-71-8		tr-0.2	0.1-1.2			
7-epi-γ-Eudesmol	117066-77-0		0.1-0.8	0.1-0.7			
(*E,E*)-α-Farnesene	502-61-4						2.6[b]
β-Farnesene	502-60-3			0.1-0.7			
(*E*)-β-Farnesene	18794-84-8		0.1-0.8				+[f]
(*Z*)-β-Farnesene	28973-97-9						<0.1[e]; 7.1[b]
α-Fenchene	471-84-1	0.01-0.05			0.05		
Germacrene B	15423-57-1		tr-0.3	0.1-0.6	0.4		0.1[g];
Germacrene D	23986-74-5	0.2-1.4	0.2-0.9	0.2-1.0	0.6	9.1[b];	+[f]; 0.1[e]; 0.3[g]
lactone							
Heptadecanolide	5637-97-8		0.2-0.5	0.2-2.9	0.4	0.06	+[f]; +[d]
Heptanal	111-71-7	0.03-0.06				tr	
Hexanal	66-25-1	0.04-0.08				tr	
Hexadecanolide	109-29-5		0.1	0.1-0.5			+[d]
β-Himachalene	1461-03-6						+[f]; 0.2[g]
α-Humulene	6753-98-6	0.4-1.7	0.9-1.7	0.4-1.4	0.5	1.1	+[f]; 0.4[e]; 0.6[c,g]
β-Humulene	116-04-1						0.3[b]
Humulene epoxide II	19888-34-7		0-0.3			0.1	
α-Humulene oxide	96638-51-6	0.09-0.3		0.2-0.5	0.4		
Humulenol (II)	19888-00-7				0.09		
Imperatorin	482-44-0						+[a]
Isoamyl benzoate	94-46-2		0.1-0.4				
Isoamyl benzyl ether	122-73-6			0.1-0.3			
Isobornyl acetate	125-12-2						1.2[g]
Isobutylbenzene	538-93-2				0.5		
Isoterpinolene	586-63-0					0.3	0.3[e]
Limonene	138-86-3	6.4-15.0	0-9.2	0-8.8	6.6	5.9	+[f]; 8.4[e]; 10.0[c]; 16.4[g]
cis-Limonene epoxide	13837-75-7						0.1[e]
Limonene-1,2-oxide	1195-92-2						+[f]
Linalool	78-70-6				0.1		+[f]; 0.1[e]
Longicyclene	1137-12-8				0.07		
Longipinanol	66141-14-8			0.4-4.2			
p-Mentha-1(7),5-di-en-2-ol	30681-15-3						0.3[e]
p-Mentha-2,8-diene	499-99-0				1.6		
trans-*m*-Mentha-2,8-diene			0-1.5				
trans-*p*-Mentha-2,8-diene	5113-87-1	0.2-0.8		0-1.5			
p-Mentha-1,5-dien-8-ol	1686-20-0		tr-0.5	0.1-2.6			
cis-*p*-Menth-4-ene-1,2-diol							0.2[e]
cis-*p*-Menth-2-en-1-ol	29803-82-5	0.06-0.1	0-0.3	0-0.5	0.5	0.1	+[f]; 0.1[e]; 0.3[g]
trans-*p*-Menth-2-en-1-ol	29803-81-4	0.1-0.6	0-0.4	0-0.4	0.09	0.07	+[f]; 0.1[e]; 0.2[g];
Menthol	89-78-1		tr-0.2	0.1-0.3			
Menthone	89-80-5				0.08		
3-Methylcyclopenta-decanone	541-91-3						0.9[c]
13-lactone							
12-Methyl-13-trideca-nolide	57092-32-7		0.1-0.5	0.1-0.9	tr	0.06	+[f]; +[d]
α-Muurolene	10208-80-7		0.2-0.9	0.2-1.1	0.1	0.4	+[f]; 0.1[e]; 0.3[g]; 1.5[c]
γ-Muurolene	30021-74-0		0.1-0.5	0.2-0.4		0.6	
α-Muurolol	104245-48-9		tr-0.6	0.1-0.4	0.08		
τ-Muurolol	19912-62-0				0.03		
Myrcene	123-35-3	1.4-5.4	1.4-3.4	0.4-3.0	5.3	2.8	+[f]; 4.6[b]; 4.8[e]; 5.5[g]; 13.1[c]
Myrtenal	564-94-3		tr-0.6	0.1-0.5			
Myrtenol	515-00-4		tr-0.5	tr-0.4			
Myrtenyl acetate	1079-01-2		0-0.2	0-0.4			
(*E*)-Ocimene	27400-72-2						+[f]
(*Z*)-Ocimene	27400-71-1						+[f]
(*E*)- β-Ocimene	3779-61-1	0-5.9	0.1-0.7	0.1-0.5	tr	2.3	1.7[e]; 3.1[b]; 3.4[c]; 5.1[g];
(*Z*)-β-Ocimene	3338-55-4	0.7-4.6			0.05	0.9	0.8[e]; 1.3[b]; 1.8[g]
n-Octanal	124-13-0	0.04-1.0					
Osthole	484-12-8		1.2-5.3	1.5-8.8			+[f]; 1.0[c]
14-Pentadecanolide							0.4[e]
2-Pentylfuran	3777-69-3						+[f]
Perillyl alcohol	536-59-4				0.1		

Table 5.2.1 Constituents identified in angelica root oils (*continued*)

Constituent	CAS	Percentage and range					
		A	B (9)	C (11)	D (5)	E (3)	F
Phellandral	21391-98-0						+[f]
α-Phellandrene	99-83-2	4.5-22.0	2.1-9.1	0.7-9.1	2.0	19.1	+[f]; 1.7[e]; 1.9[b]; 4.3[c]; 8.7[g]
β-Phellandrene	555-10-2	9.4-18.7	0.1-18.5	tr-15.4	1.3	26.6	+[f]; 10.1[e]; 14.5[c]; 30.5[b]
α-Pinene	80-56-8	11.4-27.0	11.2-20.8	3.8-19.4	32.2	15.7	+[f]; 21.0[c]; 21.3[g]; 23.6[b]; 24.5[e]
β-Pinene	127-91-3	0.2-3.2	0.2-3.2	0.2-3.1	1.5	1.1	+[f]; 1.3[g]; 1.4[b,e]
α-Pinene oxide	1686-14-2						0.1[e]
cis-Piperitol	16721-38-3		0-1.0	0-0.1		tr	+[f]; 0.1[e]; 0.2[g]
trans-Piperitol	16721-39-4				0.3	tr	+[f]; 0.2[g]
Piperitone	89-81-6						+[f]
Psoralen	66-97-7						+[f]; 0.3-1.3[a]
Rosefuran	15186-51-3						0.1[e]
Sabina ketone	513-20-2						+[f]
Sabinene	3387-41-5	0.6-11.3	1.1-7.5	2.1-7.5	0.5	0.7	+[f]; 5.1[g]; 6.3[e]
trans-Sabinene hy-drate	17699-16-0		0.03-0.4			0.06	
Sabinol							+[f]
Sabinyl acetate	53833-85-5			0.1-0.5	0.2		+[f]; 0.2[e]
trans-Sabinyl acetate	139757-62-3		0-0.4				
β-Selinene	17066-67-0		tr-0.5	tr			
β-Sesquiphellandrene	20307-83-9						+[f]
Spathulenol	6750-60-3		0.1-0.4	0.2-0.6	0.1		0.1[c]
Sylvestrene	1461-27-4						0.2[e]
α-Terpinene	99-86-5	0.08-0.9	0.1-2.7	0.1-2.0	0.3	0.1	+[f]; 0.7[g]
γ-Terpinene	99-85-4	0.4-3.0	0.5-3.0	0.4-2.4	3.1	0.3	+[f]; 0.4[e]; 1.3[g]
Terpinen-4-ol	562-74-3	0.07-1.5	0.3-1.5	0.9-5.1	0.08	0.09	+[f]; 0.5[g]; 1.0[e]
α-Terpineol	98-55-5		tr-0.4	0.1-0.7	0.4	tr	+[f]
Terpinolene	586-62-9	0.3-2.3	0.9-2.3	0.5-1.9	0.9	0.5	+[f]; 0.3[e]; 1.4[g]
(14-)Tetradecanolide	3537-83-5						+[d]
Thuja-2,4(10)-diene	36262-09-6					0.1	0.3[g]; 0.5[e];
α-Thujene	2867-05-2	0.04-0.8	tr-0.3	t-0.2	0.1	0.4	+[f]; 0.8[g]; 1.3[e];
Toluene	108-88-3	0.04-0.1					
Tricyclene	508-32-7	0.01-0.04			0.04		
13-Tridecanolide	1725-04-8	0.08-0.8	1.4-2.9	1.5-6.1	0.6	0.7	+[f]; +[d]; 0.5[c]
15-Tridecanolide							+[a]
(3*E*,5*Z*)-1,3,5-Undeca-triene	19883-27-3						0.1[e]
5-Undecen-3-yne	74744-31-3						+[f]
cis-Verbenol	1845-30-3	0.07-0.5	0.1-0.5	0.2-0.8		tr	0.2[g]
trans-Verbenol	1820-09-3	0.1-1.2	0.2-0.6	0.4-1.1		0.2	
Verbenyl acetate	33522-69-9				0.4		
Zingiberene	495-60-3		0.1-0.8	0.1-0.5			+[f]

A thirty-one angelica root essential oil samples from France, Hungary, Poland, Germany and Netherlands analyzed between 1997 and 2013; lowest and highest concentrations given (E. Schmidt, unpublished data)

B thirteen lab-distilled essential oils from the roots of wild Lithuanian angelica from four habitats collected between 1996 and 2002; lowest and highest concentrations given (ref. 9)

C six lab-distilled oils from wild angelica collected in two places in Lithuania, 2 were stored for 2.5 months; lowest and highest concentrations given (ref. 11)

D one lab steam-distilled angelica root oil from angelica harvested in the Auvergne, France (ref. 5)

E one batch of oil obtained by steam-distillation of fresh roots in a commercial Canadian distillation unit (ref. 3)

F data from other studies (indicated with superscript letters); highest concentrations found in any study reviewed here given; when two or more oils were investigated, only the highest concentrations are mentioned, unless indicated otherwise

[a] data cited in ref. 11; [b] one lab steam-distilled oil from wild growing Siberian *Angelica*; the composition of this oil was different from usual angelica root oils, so possibly the plant examined may have been another species from the genus *Angelica* than *Angelica archangelica* (ref. 10); [c] four lab-hydrodistilled oils obtained from the roots of young cultivated *Angelica archangelica* plants in Brazil with distillation times varying from 2 to 24 hours (ref. 7); [d] one commercial angelica root oil from France (ref. 8); [e] one commercial *Angelica archangelica* root oil from China (ref. 13); [f] one oil from dried angelica roots purchased in Germany obtained by steam-distillation followed by liquid-liquid extraction with a mixture of dichloromethane and pentane 1:9; as the amounts were expressed in mg/kg, the presence of the chemicals in the oil is indicated with +[f] (ref. 14); [g] one lab-hydrodistilled oil from the roots of Italian cultivated *A. archangelica* (ref. 16)

tr: trace (columns B and C: <0.1; column D: <0.03; column E: <0.06); + present in the oil investigated, but quantity not stated or in a manner which cannot be compared to the other data

Table 5.2.2 Major constituents of angelica root oils

Constituent	CAS	Percentage and range					
		A	**B (9)**	**C (11)**	**D (5)**	**E (3)**	**F**
α-Pinene	80-56-8	11.4-27.0	11.2-20.8	3.8-19.4	32.2	15.7	21.0[c]; 21.3[g]; 23.6[b]; 24.5[e]
β-Phellandrene	555-10-2	9.4-18.7	0.1-18.5	tr-15.4	1.3	26.6	10.1[e]; 14.5[c]; 30.5[b]
α-Phellandrene	99-83-2	4.5-22.0	2.1-9.1	0.7-9.1	2.0	19.1	1.7[e]; 1.9[b]; 4.3[c]; 8.7[g]
δ3-Carene	13466-78-9	6.4-17.5	10.6-16.9	3.4-16.0	16.3	5.7	0.3[b]; 13.7[c]; 13.8[e]; 16.5[g]
Limonene	138-86-3	6.4-15.0	0-9.2	0-8.8	6.6	5.9	8.4[e]; 10.0[c]; 16.4[g]
Myrcene	123-35-3	1.4-5.4	1.4-3.4	0.4-3.0	5.3	2.8	4.6[b]; 4.8[e]; 5.5[g]; 13.1[c]
Sabinene	3387-41-5	0.6-11.3	1.1-7.5	2.1-7.5	0.5	0.7	5.1[g]; 6.3[e]
p-Cymene	99-87-6	1.3-8.4	1.5-10.6	0.6-3.9	6.4	5.0	2.2[g]; 6.2[c]; 8.8[e]
(*E*)- β-Ocimene	3779-61-1	0-5.9	0.1-0.7	0.1-0.5	tr	2.3	1.7[e]; 3.1[b]; 3.4[c]; 5.1[g];
(*Z*)-β-Ocimene	3338-55-4	0.7-4.6			0.05	0.9	0.8[e]; 1.3[b]; 1.8[g]
Bornyl acetate	76-49-3	0.3-3.2	1.8-4.3	2.4-4.2	1.8	0.1	0.4[e]; 0.8[c]

LEGEND: SEE UNDER TABLE 5.2.1

CONTACT ALLERGY/ALLERGIC CONTACT DERMATITIS

General

Contact allergy to/allergic contact dermatitis from angelica root oil has been reported in two publications only. Data on angelica oil (plant part used not specified) are presented in Chapter 5.1 Angelica fruit oil.

Testing in groups of patients

A group of 86 patients from Poland previously reacting to the fragrance mix was tested with angelica root oil and two (2.3%) had a positive patch test reaction; relevance data were not provided (16).

Case reports

A patient developed allergic contact dermatitis from the perfume in an eye cream; she was patch tested with all 94 components of the perfume and reacted to angelica root oil (test concentration unknown) and eleven of the other chemicals in the perfume (17).

LITERATURE

1. Bhat ZA, Kumar D, Shah MY. *Angelica archangelica* Linn. is an angel on earth for the treatment of diseases: a review. Int J Nutr Pharm Neurol Dis 2011;1:35-49
2. Sigurdsson S, Geirsson G, Gudmundsdottir H, Egilsdottir PB, Gudbjarnason S. A parallel, randomized, double-blind, placebo-controlled study to investigate the effect of SagaPro on nocturia in men. Scand J Urol 2013;47:26-32
3. Lopes D, Strobl H, Kolodziejczyk P. 14-Methylpentadecano-15-lactone (Muscolide): A new macrocyclic lactone from the oil of *Angelica archangelica* L. Chem Biodivers 2004;1:1880-1887
4. Sarker SD, Nahar L. Natural medicine: the genus *Angelica*. Curr Med Chem 2004;11:1479-500
5. Chalchat J-C, Garry R-P. Essential oil of angelica roots (*Angelica archangelica* L.): Optimization of distillation, location in plant and chemical composition. J Essent Oil Res 1997;9:311-319
6. Nivinskiene O, Butkiene R, Mockute D. The seed (fruit) essential oils of *Angelica archangelica* L. growing wild in Lithuania. J Essent Oil Res 2007;19:477-481
7. Paroul N, Rota L, Frizzo C, Atti dos Santos AC, Moyna P, Gower AE, Atti Serafini L, Cassel E. Chemical composition of the volatiles of *Angelica* root obtained by hydrodistillation and supercritical CO_2 extraction. J Essent Oil Res 2002;14:282-285
8. Schultz K, Kraft P. Characterization of the macrolide fraction of *Angelica* root oil and enantiomeric composition of 12-methyl-13-tridecanolide. J Essent Oil Res 1997;9:509-514
9. Nivinskienė O, Butkienė R, Mockutė D. The chemical composition of the essential oil of *Angelica archangelica* L. roots growing wild in Lithuania. J Essent Oil Res 2005;17:373-377
10. Shchipitsyna OS, Efremov AA. Composition of ethereal oil isolated from various vegetative parts of *Angelica* from the Siberian region. Russ J Bioorg Chem 2011;37:888-892
11. Nivinskienė O, Butkienė R, Mockutė D. Changes in the chemical composition of essential oil of *Angelica archangelica* L. roots during storage. Chemija (Vilnius) 2003;14:52-56
12. Lawrence BM. Progress in essential oils. Angelica root and seed oils. Perfum Flavor 1999;24:47-49
13. Wedge DE, Klun JA, Tabanca N, Demirci B, Ozek T, Can Baser KH, et al. Bioactivity-guided fractionation and GC/MS fingerprinting of *Angelica sinensis* and *Angelica archangelica* root components for antifungal and mosquito deterrent activity. J Agric Food Chem 2009;57:464-470
14. Nykänen I, Nykänen L, Alkio M. Composition of angelica root oils obtained by supercritical $C0_2$ extraction and steam distillation. J Essent Oil Res 1991;3:229-236
15. Fraternale D, Flamini G, Ricci D. Essential oil composition and antimicrobial activity of *Angelica archangelica* L. (Apiaceae) roots. J Med Food 2014;17:1043–1047
16. Rudzki E, Grzywa Z. Allergy to perfume mixture. Contact Dermatitis 1986;15:115-116
17. Larsen WG. Cosmetic dermatitis due to a perfume. Contact Dermatitis 1975;1:142-145

Chapter 5.3 ANISEED OIL

DEFINITION

Aniseed oil (essential oil of aniseed) is the essential oil obtained from the fruit of the anise, *Pimpinella anisum* L.

INCI NOMENCLATURE

Description/definition: Pimpinella anisum fruit oil is the essential oil obtained from the dried ripe fruits of the anise, *Pimpinella anisum* L., Umbelliferae (Apiaceae)

INCI name EU: Pimpinella anisum fruit oil

INCI name USA: Pimpinella anisum (anise) fruit oil

CAS registry number(s): 8007-70-3; 84775-42-8

EINECS number(s): 283-872-7

ISO (INTERNATIONAL ORGANIZATION FOR STANDARDIZATION) STANDARD

ISO number: 3475

ISO name: Essential oil of aniseed

Botanical origin: *Pimpinella anisum* L.

Parts of plant used: Fruit

ISO values: ISO values (minimum and maximum concentrations) are shown in Table 5.3.1.

Aniseed oil should not be confused with star anise oil, obtained from *Illicium verum* (Chapter 5.81).

THE PLANT, THE OIL, AND THEIR USES

Pimpinella anisum L. is a herbaceous annual plant growing to one meter tall or higher. It probably originates from the eastern Mediterranean region and south-west Asia and is widely cultivated in the Mediterranean rim, Russia, South Africa, and Brazil (1,3, GRIN Taxonomy for Plants). Western cuisines have long used anise to flavor some dishes, drinks, and candies. Anise is an essential ingredient in certain spirits such as arak, absinthe, anisette, pastis, ouzo, sambuca, and raki (4). The fruits (commercially called seeds [aniseeds]) are said to be antiseptic, antispasmodic, carminative, digestive, expectorant, stimulant, muscle relaxant, analgesic, anticonvulsant and stomachic (11). They are used in herbal medicine for the treatment of asthma, coughs and pulmonary afflictions as well as digestive disorders such as wind, bloating, colic, nausea and indigestion. It was also reported that extracts from anise fruits have therapeutic effects on several conditions, such as gynecological and neurological disorders. It has mild estrogenic effects, which explains the use of this plant in folk medicine for increasing milk secretion, dysmenorrhea and menopausal hot flushes in women. In diabetic patients, aniseeds may show hypoglycemic and hypolipidemic effect (1,6,9,11). Aniseed is also used as a breath freshener.

The essential oil obtained from the fruits is used in perfumery, toothpastes, medicinally, as a food flavoring and as an insecticide against head-lice and mites (3). It is also utilized in aromatherapy (37), though some warn about its toxicity (38). The pharmacological activities of *Pimpinella anisum* have been reviewed (6,13). The European Medicines Agency recently concluded that ‘Medicinal use of aniseed and anise oil is not supported by clinical evidence’ (32).

CHEMICAL COMPOSITION

Aniseed oil is a clear, more or less mobile liquid or solid crystalline mass, which has a spicy and sweet odor from the high amounts of anethole. The yield of essential oil from the fruits of *Pimpinella anisum* L. generally varies from 1.5 to 6.0%. The main producing countries of this oil are China, Spain, Egypt, France and Italy. Literature data (up to November 2, 2014) on the chemical composition of aniseed oils and unpublished analytical data from one of us (E.S.) are shown in Table 5.3.2 in alphabetical order. In aniseed oils from various origins, over 120 chemicals have been identified. About 47% of these were found in a single reviewed publication only.

The major compounds found in aniseed oils from different sources are shown in Table 5.3.3. Aniseed oil is always dominated by (*E*)-anethole with concentrations up to 96.3%. Other important components (maximum concentrations shown) may be methyl chavicol (20.2%; an extremely high 85.3% is probably erroneous), γ-himachalene (15.2%) and *p*-anisaldehyde (5.4%). Well-known ingredients of aniseed oils that were present in concentrations of 4% or higher in one or two studies were *trans*-pseudoisoeugenyl 2-methylbutyrate (6.4% and 12.7%), limonene (9.8%) and (*Z*)-anethole (7.4%). Uncommon or rare constituents of aniseed oil found in high concentrations in single studies include α-longipinene (10.1%), fenchone (5.0 and 6.2%), 3,4-dimethoxystyrene (5.2%) and cyclosativene (5.2%).

Commercial oils

The ten chemicals that had the highest maximum concentrations in 81 commercial aniseed essential oil samples (concentration ranges provided) are the following: (*E*)-anethole (91.0-98.6%), limonene (0.01-3.5%), methyl chavicol (0.01-3.2%), γ-himachalene (1.4-2.9%), *p*-anisaldehyde (0.1-1.4%), *p*-methoxyphenylacetone (0-1.4%), *trans*-pseudoisoeugenyl 2-methylbutyrate (0.4-1.3%), *p*-anisic acid (0-0.9%), α-zingiberene (0.2-0.5%) and (*Z*)-anethole (0.03-0.3%) (Erich Schmidt, unpublished analytical data).

As (*E*)-anethole dominates aniseed oil, all oxidation products of anethole (anisyl alcohol, anisaldehyde, anisic acid, anethole epoxide, *p*-methoxyphenylacetone, *p*-methoxypropiophenone, anisyl ketone) may be present in aniseed oils. The presence of these compounds can be an indication of the deterioration of the oil (3).

CONTACT ALLERGY/ALLERGIC CONTACT DERMATITIS

General

Contact allergy to/allergic contact dermatitis from aniseed oil has been reported in a few studies, including some patients with occupational allergic contact dermatitis. In a case report, anethole may have been the allergen in aniseed oil.

Table 5.3.1 ISO values (%) for aniseed oil[a]

Compound	CAS	Minimum	Maximum
(*E*)-Anethole	4180-23-8	87.0	94.0
γ-Himachalene	53111-25-4	1.0	5.0
Methyl chavicol	140-67-0	0.5	3.0
trans-Pseudoisoeugenyl 2-methylbutyrate	58989-20-1	0.3	2.0
p-Anisaldehyde	123-11-5	0.1	1.4
(*Z*)-Anethole	25679-28-1	0.1	0.4

[a] ISO 3475 Essential oil of aniseed ©ISO 2002; Geneva, Switzerland, www.iso.org

Testing in groups of patients

In a group of 21 patients with dermatitis caused by fragrances and tested with a series of essential oils, one (5%) reacted to 'anise oil' 2%; relevance data were not provided (44).

Case reports and positive patch tests

One patient had psoriasis-like dermatitis from contact allergy to aniseed oil (39). Two patients working in the food industry developed occupational allergic contact dermatitis from aniseed oil (tested 5% olive oil) and its main ingredient anethole (41). One case of dermatitis and stomatitis was caused by contact allergy to aniseed

Table 5.3.2 Constituents identified in aniseed oils

Constituent	CAS	Percentage and range					
		A	B (14)	C (3)	D (9)	E (16)	F
Acetanisole	5451-83-2					0.2	0.9[m]
Alismol	87827-55-2						0.6[b]
α-Amorphane			0-0.2		0.2		0.2[s,w]
(*E*)-Anethole	4180-23-8	91.0-98.6	81.2-91.5	76.9-93.7	90.2	89.5	87.6[z]; 90.1[y]; 93.9[h]; 94.2[g]; 94.4[v]; 95.3[q]; 96.2[u]; 96.3[j]
(*Z*)-Anethole	25679-28-1	0.03-0.3	0.1-0.2	0-2.0	0.2	0.1	0.2[w]; 0.5[j]; 0.6[h]; 2.1[b]; 2.3[m]; 7.4[o]
p-Anisaldehyde	123-11-5	0.1-1.4		0-5.4		0.5	0.6[r]; 0.7[f]; 0.9[m]; 1.9[e]; 2.1[a]; 2.9[b]
p-Anisaldehyde di-methyl acetal	2186-92-7						0.8[j] (artifact)
Anisic acid	1335-08-6					0.1	
p-Anisic acid	100-09-4	0.0-0.9					
p-Anisyl acetone	104-20-1						0.2[b]; 0.3[l]; 1.1[a]
Anisyl alcohol	1331-81-3					0.09	
Aromadendrene	489-39-4						0.1[c]
1*H*-Benzocycloheptene							0.2[z]
cis-α-Bergamotene	18252-46-5						0.1[a]
trans-α-Bergamotene	13474-59-4	0.03-0.2					tr[q]; 0.6[a]
Biisocrotyl	764-13-6						0.09[f]
(*Z*)-α-Bisabolene	29837-07-8						0.2[c]; 1.8[c]
β-Bisabolene	495-61-4	0.2-0.3	0.1-0.9	0-0.6	0.5		0.1[a]; 0.2[g]; 0.3[h]; 0.4[w]; 0.6[k]; 0.7[b]
β-Bourbonene	5208-59-3			0-0.9			
Butanoic acid, 2 methyl-, 4-methoxy-2-(3-methyloxiranyl) phenyl ester	97180-28-4						0.3[l]
γ-Cadinene	39029-41-9			0-0.3			
δ-Cadinene	483-76-1			0-0.3			tr[q]
ω-Cadinene	17627-21-3						0.07[a]
α-Cadinol	481-34-5						0.08[w]; 0.1[s]; 0.2[a]
α-Calacorene	21391-99-1						tr[q]
Camphene	79-92-5					<0.01	tr[x]; 0.1[m]
Camphor	76-22-2						0.2[o,s,y]
δ3-Carene	13466-78-9					0.01	tr[q]; <0.05[m]; 0.1[a]; 0.3[t]
Carvone	99-49-0						0.7[c]
Carvotanacetone	499-71-8						2.5[z]
β-Caryophyllene	87-44-5	0.0-0.2					<0.01[q]; 0.2[f]; 0.3[b]; 1.3[a]
1,8-Cineole	470-82-6					<0.01	0.02[r]; 0.1[m,p,y]; 0.2[a]
α-Copaene	3856-25-5						<0.01[q]
α-Cuparene							0.1[h,i]
Curcumene	644-30-4	0.1-0.2		0-0.4			<0.01[q]; 0.2[c]; 1.4[b]
Cyclosativene	22469-52-9		0-0.1		0.1		0.1[w]; 5.2[o]
p-Cymene	99-87-6	0.01-0.02				0.1	0.01[q]; <0.1[b]; 0.1[m,p]; 0.2[a]; 0.5[t]
5,6-Diethenyl-1-methylcyclohexene							0.06[f]
Di-α-furylmethane	1197-40-6						0.2[f]

Table 5.3.2 Constituents identified in aniseed oils (*continued*)

Constituent	CAS	Percentage and range					
		A	B (14)	C (3)	D (9)	E (16)	F
Dihydrocarvone	5948-04-9						0.3[z]
cis-Dihydrocarvone	3792-53-8						0.1[c]
Dill apiole	484-31-1						1.1[z];
3,4-Dimethoxystyrene	6380-23-0						5.2[f]
1,2-Dimethylindan	17057-82-8						0.08[f]
Elemene	11029-06-4						0.2[f]
β-Elemene	33880-83-0		0-0.1		0.1		0.02[q]; 0.04[a]; 0.06[r]; 0.1[w]; 0.2[s]
δ-Elemene	20307-84-0	0.05-0.2	0-0.5		0.5		0.06[q]; 0.1[c]; 0.3[k]; 0.5[s,w]; 1.3[b]
trans-Epoxypseudo-isoeugenyl 2-methyl-butyrate	125028-84-4			0-2.3			0.1[q]; 0.3[r]; 2.1[b]
α-Ethyl-*p*-anisyl alcohol							0.3[f]
Ethyl hexadecanoate	628-97-7						0.04[f]
Ethyl oleate	111-62-6						0.9[f]
γ-Eudesmol (selinenol)	1209-71-8						0.08[a]
Eugenyl acetate	93-28-7						3.9[k]
α-Farnesene	502-61-4			0-0.4			
(*E,E*)-α-Farnesene	502-61-4						0.2[a]
β-Farnesene	502-60-3			0-0.7			
(*E*)-β-Farnesene	18794-84-8	0.02-0.06					
(*E*)-β-Farnesol	106-28-5						<0.05[m]
Fenchone	1195-79-5						5.0[p,y]; 6.2[x];
α-Fenchyl acetate	111821-74-0						0.1[o,y]
Foeniculin (*E*-)	78259-41-3						3.3[a]
Geijerene	6902-73-4						0.02[q]; 0.04[r]; 0.4[b]
Geraniol	106-24-1						0.06[a]; 0.4[b]
Germacrene B	15423-57-1						<0.01[q]
Germacrene D	23986-74-5			0-1.1			0.8[d]
α-Gurjunene	489-40-7						4.0[f]
Hexadecanoic acid	57-10-3						0.3[g]
α-Himachalene	3853-83-6	0.1-0.3	0.1-0.8	0-0.4	0.9		0.2[h]; 0.3[k]; 0.5[f]; 0.7[w]; 1.0[s]; 1.7[b]
β-Himachalene	1461-03-6	0.05-0.2	0.1-0.5		0.5		0.2[r]; 0.3[k]; 0.4[w]; 0.5[s]; 0.8[z]; 1.8[b]
γ-Himachalene	53111-25-4	1.4-2.9	1.9-7.9	0.4-8.2	8.3		1.8[z]; 2.3[h]; 3.5[k]; 7[w]; 12.3[s];15.2[b]
α-Humulene	6753-98-6						0.2[a]; 1.1[t]
3-Hydroxycarbofuran	16655-82-6						0.8[f]
Isoeugenol	97-54-1					0.2	
o-Isoeugenol	1076-55-7						1.9[l]
Isogeijerene	5975-49-5			0-0.9			<0.01[q]; <0.1[b]
Isoledene	95910-36-4						3.3[o]
Limonene	138-86-3	0.01-3.5					0.3[b]; 0.8[c,]; 1.3[t]; 1.4[z]; 1.5[a]; 9.8[x]
Linalool	78-70-6	0.01-0.1	0-0.6		0.2	0.8	0.2[m]; 0.3[f,l]; 0.6[b]; 0.9[s]; 2.3[a]
Linalyl acetate	115-95-7					<0.01	
Linoleic acid	60-33-3						tr[x]
α-Longipinene	5989-08-2						0.01[q]; 0.08[f]; 10.1[o]
Menthol	89-78-1						0.1[j]
p-Methoxyphenyl-acetone	122-84-9	0.0-1.4					0.1[r]
Methyl chavicol	140-67-0	0.01-3.2	0.3-1.2	0.5-2.3	0.8	0.8	3.6[f]; 7.3[a]; 8.8[t]; 20.2[b]; 85.3[x]
Methyl eugenol	93-15-2		0-0.1			0.6	0.09[z]; 0.1[i]
1-Methylguanine	938-85-2						0.1[f]
(*E*)-Methylisoeugenol	6379-72-2		0.1-0.3		0.2		0.1[s]; 0.2[w]
Methyl 1-phenylallyl ether	22665-13-0						1.7[f]
β-Monopalmitin	23470-00-0						0.2[f]
α-Muurolene	10208-80-7		0-0.1		0.2		0.2[s,w]
γ-Muurolene	30021-74-0						0.5[b]; 1.1[d]
Myrcene	123-35-3	0.0-0.07				<0.01	tr[y]; <0.05[m,p]; 0.06[a]; 0.3[t]
(*E*)-Nerolidol	40716-66-3						0.1[a]
Nonanal	124-19-6			0-1.4			
(*E*)-β-Ocimene	3779-61-1					<0.01	<0.05[m]
(*Z*)-β-Ocimene	3338-55-4					<0.01	tr[y]; <0.05[m,p]
Oleic acid	112-80-1						0.5[f]

Table 5.3.2 Constituents identified in aniseed oils (*continued*)

Constituent	CAS	Percentage and range					
		A	B (14)	C (3)	D (9)	E (16)	F
Osmorhizole	3698-23-5						0.8[b]
α-Phellandrene	99-83-2					0.02	tr[y]; <0.05[p]; 0.1[m]; 0.4[a]; 0.6[t]
β-Phellandrene	555-10-2					<0.01	tr[q]; 0.1[m]; 0.2[a]
α-Pinene	80-56-8	0.01-0.1				<0.01	0.01[q]; 0.1[p,s]; 0.2[m]; 0.5[a]; 1.1[t]
β-Pinene	127-91-3	0.01-0.02				<0.01	tr[q]; 0.04[a]; <0.05[m]
Pregeijerene	20082-17-1			0-0.5			0.02[q,r]; 0.1[b]
cis-Pseudoisoeugenyl 2-methylbutyrate							2.3[e]
trans-Pseudoisoeuge-nyl 2-methylbutyrate	58989-20-1	0.4-1.3		0.4-6.4			0.4[e]; 0.7[g,q]; 1.6[r]; 12.7[b]
Sabinene	3387-41-5					<0.01	tr[q,y]; <0.05[m,p]
Safrole	94-59-7						0.6[m,n]; 2.5[o]
β-Sesquiphellandrene	20307-83-9	0.05-0.2	0-0.2	0-0.4	0.1		<0.01[q]; 0.09[s]; 0.1[c,w,z]; 0.3[k]
Spathulenol	6750-60-3						0.08[s]; 0.1[w]
(-)-Spathulenol (β-)	77171-55-2		0-0.2		0.1		<0.1[b]; 0.2[f]
α-Terpinene	99-86-5					<0.01	<0.05[m]; 0.1[a]; 0.2[f]
γ-Terpinene	99-85-4					0.09	0.01[q]; 0.08[a]; 0.1[b,s]; 0.6[t]
Terpinen-4-ol	562-74-3					0.5	<0.05[m]; <0.1[b]; 0.3[a]
α-Terpineol	98-55-5					1.0	0.1[m]; 0.2[a]
Terpinolene	586-62-9					0.04	<0.05[m]; 0.08[a]
1,2,4-Trimethylene-cyclohexane	14296-81-2						0.1[f]
Valencene	4630-07-3						0.2[g]
Viridiflorene (ledene)	21747-46-6						0.1[a]
α-Ylangene	14912-44-8						0.01[q]; 0.2[f]; 0.3[b]
α-Zingiberene	495-60-3	0.2-0.5	0.2-1.3	0-1.1	1.0		0.4[c,s]; 0.8[w]; 1.2[d]; 2.1[b]; 2.9[k]

A eighty-one aniseed essential oil samples from China, Italy, Spain and France analyzed between 1998 and 2013; lowest and highest concentrations given (E. Schmidt, unpublished data)

B fifteen lab-hydrodistilled oils from the aniseeds of 15 accessions of *P. anisum* cultivated in Germany; lowest and highest concentrations given (ref. 14)

C fourteen lab-hydrodistilled aniseed oils from *Pimpinella anisum* plants from 11 European countries (ref. 3)

D six oils from fruits of *P. anisum* of three cultivars grown on two localities in Germany; highest concentrations given (ref. 9)

E twenty-nine oils from seed sources from various parts of Turkey; average concentrations for all oils given (ref. 16)

F data from other studies (indicated with superscript letters); highest concentrations found in any study reviewed here given; when two or more oils were investigated, only the highest concentrations are mentioned, unless indicated otherwise

[a] one lab-distilled oil from fruit of *P. anisum* cultivated in Poland (ref. 10); [b] four lab-distilled (two classical, two microwave-assisted) oils from Turkish *P. anisum* fruit, whole and ground (ref. 15); [c] one lab-hydrodistilled aniseed oil from fruits of plants cultivated in Iran (ref. 26); [d] one lab-hydrodistilled oil from the fruits of plants cultivated in Iran from Hungarian seeds (ref. 2); [e] one steam-distilled aniseed oil from Turkey (ref. 5); [f] one lab-hydrodistilled oil from Turkish aniseeds (ref. 7); [g] one lab-hydrodistilled oil from aniseeds of wild growing *P. anisum* in Turkey (ref. 8); [h] one lab-distilled oil from aniseeds purchased in Egypt (ref. 12); [i] one lab-hydrodistilled oil from Turkish aniseeds (ref. 11); [j] one lab-hydrodistilled oil from Argentinian *P. anisum* fruits (ref. 25); [k] one lab-hydrodistilled oil from fruits in the ripening phase from plants grown in Iran of Hungarian seeds (ref. 24); [l] one lab-hydrodistilled oil of seeds of *P. anisum* of Algerian origin (ref. 1); [m] one aniseed oil (ref. 17); [n] incorrect identification (ref. 20); [o] one commercial aniseed oil; on the basis of the high concentration of (*Z*)-anethole (7.4%), the authors suggested the oil had been obtained from the whole plant rather than from the fruits (ref. 18); BM Lawrence (ref. 20) suggested that safrole, α-longipinene, cyclosativene and isoledene had been incorrectly identified; [p] one lab hydrodistilled oil from fruits purchased at a local Indian market (ref. 19); [q] one lab-prepared aniseed oil (ref. 22); [r] one lab-distilled oil and a Spanish commercial oil (ref. 23); [s] one lab-hydrodistilled oil from dried fruits of *P. anisum* cultivated in the Czech republic (ref. 27); [t] one lab-hydrodistilled aniseed oil from South Korea (ref. 28); [u] one oil sample from the USA (ref. 29); [v] one lab-distilled aniseed oil from Greece (ref. 35); [w] three lab-prepared oils from two *P. anisum* cultivars grown in Germany (ref. 30); [x] two lab-distilled oils from aniseeds collected in the wild in Morocco and Yemen; both had an extremely atypical composition with methyl chavicol (77-85%) as dominant ingredient; a mistake (botanical misidentification?) seems very likely (ref. 31); [y] one lab-hydrodistilled oil from aniseeds purchased at a local market in India (ref. 33); [z] one lab-distilled aniseed oil from Iran (ref. 36)

tr: trace

Table 5.3.3 Major constituents of aniseed oils

Constituent	CAS	Percentage and range					
		A	B (14)	C (3)	D (9)	E (16)	F
(*E*)-Anethole	4180-23-8	91.0-98.6	81.2-91.5	76.9-93.7	90.2	89.5	94.4[v]; 95.3[q]; 96.2[u]; 96.3[j]
Methyl chavicol	140-67-0	0.01-3.2	0.3-1.2	0.5-2.3	0.8	0.8	3.6[f]; 7.3[a]; 8.8[t]; 20.2[b]; 85.3[x]
γ-Himachalene	53111-25-4	1.4-2.9	1.9-7.9	0.4-8.2	8.3		1.8[z]; 2.3[h]; 3.5[k]; 7[w]; 12.3[s];15.2[b]
p-Anisaldehyde	123-11-5	0.1-1.4		0-5.4		0.5	0.6[r]; 0.7[f]; 0.9[m]; 1.9[e]; 2.1[a]; 2.9[b]

LEGEND: SEE UNDER TABLE 5.3.2

oil in toothpaste (43). One case of occupational allergic contact dermatitis in a porcelain painter due to oil of anise, oil of turpentine and lavender oil that were mixed with pigments for painting (42). One positive patch test to aniseed oil in a patient working in a cosmetic factory, who had occupational dermatitis from a fragrance mixture he was handling daily (40).

LITERATURE

1 Saibi S, Belhadj M, El-Hadi B. Essential oil composition of *Pimpinella anisum* from Algeria. Anal Chem Lett 2012;2:401-404

2 Yamini Y, Bahramifar N, Sefidkon F, Saharkhiz MJ, Salamifar E. Extraction of essential oil from *Pimpinella anisum* using supercritical carbon dioxide and comparison with hydrodistillation. Nat Prod Res 2008;22:212-218

3 Orav A, Raal A, Arak E. Essential oil composition of *Pimpinella anisum* L. fruits from various European countries. Nat Prod Res 2008;22:227-232

4 Ertan Anli R, Bayram M. Traditional aniseed-flavored spirit drinks. Food Rev Internat 2010;26:246-269

5 Rodrigues VM, Rosa PTV, Marques MOM, Petenate AJ, Meireles MAA. Supercritical extraction of essential oil from aniseed (*Pimpinella anisum* L) using CO_2: solubility, kinetics, and composition data. J Agric Food Chem 2003;51:1518-1523

6 Shojaii A, Abdollahi Fard M. Review of pharmacological properties and chemical constituents of *Pimpinella anisum*. International Scholarly Research Network. ISRN Pharmaceutics, Volume 2012, Article ID 510795, 8 pages. doi:10.5402/2012/510795

7 Topal U, Sasaki M, Goto M, Otles S. Chemical compositions and antioxidant properties of essential oils from nine species of Turkish plants obtained by supercritical carbon dioxide extraction and steam distillation. Int J Food Sci Nutr 2008;59:619-634

8 Tabanca N, Demirci B, Ozek T, Kirimer N, Baser KHC, Bedir E, et al. Gas chromatographic–mass spectrometric analysis of essential oils from *Pimpinella* species gathered from Central and Northern Turkey. J Chromatogr A 2006;1117:194-205

9 Ullah H, Honermeier B. Fruit yield, essential oil concentration and composition of three anise cultivars (*Pimpinella anisum* L.) in relation to sowing date, sowing rate and locations. Ind Crops Prod 2013;42:489-499

10 Skalicka-Wozniak K, Walasek M, Ludwiczuk A, Głowniak G. Isolation of terpenoids from *Pimpinella anisum* essential oil by high-performance counter-current chromatography. J Sep Sci 2013;36:2611-2614

11 Özcan MM, Chalchat JC. Chemical composition and antifungal effect of anise (*Pimpinella anisum* L.) fruit oil at ripening stage. Ann Microbiol 2006;56:353-358

12 Nenaah GE, Ibrahim SIA. Chemical composition and the insecticidal activity of certain plants applied as powders and essential oils against two stored-products *Coleopteran* beetles. J Pest Sci 2011;84:393-402

13 Silano V, Delbò M. Assessment Report on *Pimpinella Anisum* L. European Medicines Agency, Evaluation of Medicines for Human Use. Doc. Ref: EMEA/HMPC/137421/2006.

14 Ullah H, Mahmood A, Ijaz M, Tadesse B, Honermeier B. Evaluation of anise (*Pimpinella anisum* L.) accessions with regard to morphological characteristics, fruit yield, oil contents and composition. J Med Plants Res 2013;7:2177-2186

15 Kürkçüoğlu M, Koşar M, Başer KHC. Comparison of microwave-assisted hydrodistillation and hydrodistillation methods for *Pimpinella anisum* L. Available at: http://bildiri.anadolu.edu.tr/papers/bildirimakale/399_417u73.pdf

16 Arslan N, Gurbuz BB, Sarihan EO, Bayrak A, Gumuscu A. Variation in the essential oil content and composition of Turkish anise (*Pimpinella anisum* L.) populations. Turk J Agric Forest 2004;28:173-177. Data cited in ref. 20

17 Ranade G. Profile. Aniseed *Pimpinella anisum* Linn. PAFAI 2007;9:81. Data cited in ref. 20

18 Dawidar AM, Mogib MA, El-Ghorab AH, Mahfouz M, Elsaid FG, Hussein KH. Chemical composition and effect of photo-oxygenation on biological activities of Egyptian commercial anise and fennel essential oils. J Essent Oil Bear Plants 2008;11:124-136

19 Singh G, Kapoor IPS, Singh P, Heluani CS, Catalan CAN. Chemical composition and antioxidant potential of essential oil and oleoresins from anise seeds (*Pimpinella anisum* L.). Internat J Essent Oil Ther 2008;2:122-130. Data cited in ref. 20

20 Lawrence BM. Progress in essential oils. Anise oil. Perfum Flavor 2011;36(October):75-76

21 Lawrence BM. Essential oils 2001-2004. Carol Stream, USA: Allured Publishing Corporation, 2006:207-212

22 Kubeczka K-H. The essential oil composition of *Pimpinella* species. In: KHC Baser and N Kirimer, Eds. Progress in essential oil research. Eskisehir, Turkey: Anadolou University Press, 1998:35-56. Data cited in ref. 21

23 Kubeczka K-H, Formacek V. Essential oils analysis by capillary gas chromatography and carbon-13 NMR Spectroscopy, 2nd edition. New York, USA: John Wiley and Sons, 2002:11-20. Data cited in ref. 21

24 Omidbaigi R, Hadjiakhoondi A, Saharkhiz M. Changes in content and chemical composition of *Pimpinella anisum* oil at various harvest time. J Essent Oil Bear Plants 2003;6:46-50

25 Gende LB, Maggi MD, Fritz R, Eguaras MJ. Antimicrobial activity of *Pimpinella anisum* and *Foeniculum vulgare* essential oils against *Paenibaccilus larvae*. J Essent Oil Res 2009;21:91-93

26 Sharifi R, Kiani H, Farzaneh M, Ahmadzadeh M. Chemical composition of essential oils of Iranian *Pimpinella anisum* L. and *Foeniculum vulgare* Miller and their antifungal activity against postharvest pathogens. J Essent Oil Bear Plants 2008;11:514-522

27 Pavela R. Insecticidal properties of *Pimpinella anisum* essential oils against the *Culex quinquefasciatus* and the non-target organism *Daphnia magna.* J Asia-Pacific Entomol 2014;17:287-293

28 Lee H-S. *p*-Anisaldehyde: Acaricidal component of *Pimpinella anisum* seed oil against the house dust mites *Dermatophagoides farina* and *Dermatophagoides pteronyssinus*. Planta Medica 2004;70:279-281

29 Zheljazkov VD, Astatkie T, O'Brocki B, Jeliazkova E. Essential oil composition and yield of anise from different distillation times. Hort Science 2013;48:1393-1396

30 Ullah H. Fruit yield and quality of anise (*Pimpinella anisum* L.) in relation to agronomic and environmental factors. PhD Thesis, Justus Liebig University Giessen, Germany. Giessen, Germany: VVB Laufersweiler Verlag, 2012

31 Al Maofari A, El Hajjaji S, Debbab A, Zaydoun S, Ouaki B, Charof R, et al. Chemical composition and antibacterial properties of essential oils of *Pimpinella anisum* L. growing in Morocco and Yemen. St Cerc St CICBIA 2013;14:11-16

32 European Medicines Agency, Committee on Herbal Medicinal Products (HMPC). Assessment report on *Pimpinella anisum* L., fructus and *Pimpinella anisum* L., aetheroleum. EMEA/HMPC/321181/2012, November 2013.

33 Singh G, Kapoor IPS, Singh P, de Heluani CS, Catalan CAN. Chemical composition and antioxidant potential of essential oil and oleoresins from anise seeds (*Pimpinella anisum* L.). Int J Essent Oil Ther 2008;2:122-130

34 Naher S, Ghosh A, Aziz S. Comparative studies on physicochemical properties and GC-MS analysis of essential oil of the two varieties of the aniseed (*Pimpinella anisum* Linn.) in Bangladesh. Int J Pharm Phytopharmacol Res 2012;2:92-95 (data not shown)

35 Kimbaris AC, Koliopoulos G, Michaelakis A, Konstantopoulou MA. Bioactivity of *Dianthus caryophyllus*, *Lepidium sativum*, *Pimpinella anisum*, and *Illicium verum* essential oils and their major components against the West Nile vector *Culex pipiens*. Parasitol Res 2012;111:2403-2410

36 Jamshidzadeh A, Hamedi A, Altalqi A, Najibi A. Comparative evaluation of analgesic activities of aniseed essential and fixed oils. Int J Pharm Res Scholars (IJPRS) 2014;3:227-235

37 Rhind JP. Essential oils. A handbook for aromatherapy practice, 2nd Edition. London: Singing Dragon, 2012

38 Davis P. Aromatherapy. An A-Z, 3rd Edition. London: Vermilion, 2005

39 Assalve D, Caraffini S, Lisi P. Psoriasis-like allergic contact dermatitis from aniseed oil. Annali Italiani di Dermatologia Clinica e Sperimentale 1987;41:411-414

40 Rudzki E, Rebandel P, Grzywa Z. Occupational dermatitis from cosmetic creams. Contact Dermatitis 1993;29:210

41 Garcia-Bravo B, Pérez Bernal A, Garcia-Hernandez MJ, Camacho F. Occupational contact dermatitis from anethole in food handlers. Contact Dermatitis 1997;37:38

42 Vente C, Fuchs T. Contact dermatitis due to oil of turpentine in a porcelain painter. Contact Dermatitis 1997;37:187

43 Loveman AB. Stomatitis venenata. Report of a case of sensitivity of the mucous membranes and the skin to oil of anise. Arch Derm Syph 1938;37:70-81

44 Meynadier JM, Meynadier J, Peyron JL, Peyron L. Formes cliniques des manifestations cutanées d'allergie aux parfums. Ann Dermatol Venereol 1986;113:31-39

Chapter 5.4 BASIL OIL, SWEET

DEFINITION

Sweet basil oil (essential oil of basil) is the essential oil obtained from the flowering aerial tops of the (sweet) basil, *Ocimum basilicum* L.

INCI NOMENCLATURE

Description/definition: Ocimum basilicum herb oil is an essential oil obtained from the herbs of the sweet basil, *Ocimum basilicum* L., Labiatae

INCI name EU: Ocimum basilicum herb oil (perfuming name, not an INCI name proper)

INCI name USA: Not in the Personal Care Products Council Ingredient Database

CAS registry number(s): 84775-71-3; 8015-73-4

EINECS number(s): 283-900-8

Description/definition: Ocimum basilicum flower/leaf extract is an extract of the flowers and leaves of the basil, *Ocimum basilicum* L., Labiatae

INCI name EU: Ocimum basilicum flower/leaf extract

INCI name USA: Ocimum basilicum (basil) flower/leaf extract

CAS registry number(s): 84775-71-3; 8015-73-4

EINECS number(s): 283-900-8

ISO (INTERNATIONAL ORGANIZATION FOR STANDARDIZATION) STANDARD

ISO number: 11043

ISO name: Essential oil of basil, methyl chavicol type

Botanical origin: *Ocimum basilicum* L.

Parts of plant used: Flowering aerial top

ISO values: ISO values (minimum and maximum concentrations) are shown in Table 5.4.1.

AFNOR (Association Française de Normalisation) values for the linalool chemotype of basil oil are shown in Table 5.4.2).

THE PLANT, THE OIL, AND THEIR USES

Ocimum basilicum L. is an aromatic, erect, almost glabrous annual herb, which grows to between 0.3 and 0.5 meters. The plant is native to India, Iran and tropical Asia, and now grows wild in tropical and sub-tropical regions (33). It is cultivated for commercial use in many countries around the world, including France, Hungary, Greece, Italy, Egypt, Morocco, Indonesia and several states in the USA (1). Basil leaves are widely used to flavor soups, meat pies, fish dishes, certain cheeses, tomato salads et cetera. It is an important seasoning in, for example, tomato paste. The leaves can be eaten as a salad. Basil is also used in perfumery, soap-making, and to flavor liqueurs (1).

The herb is widely used in systems of traditional medicine, including Ayurveda and traditional Chinese medicine.

Reported medicinal uses include the treatment of hyperlipidemia, headache, cough, cold, bronchitis, rhinitis, stomach ache, nausea, diarrhea, dysentery, constipation, flatulence, worms, kidney complaints, infections, various types of fever, rheumatism, muscle aches, gout, mental fatigue and to sooth the nerves (1,31, www.kew.org). It is also used to eliminate toxins and as a first aid treatment for wasp stings and snake bites (31). Ointments made of basil leaves are utilized for the treatment of warts, insect bites and acne (1).

Ocimum basilicum L. is the major essential oil crop around the world (3). The essential oil, which may be obtained from the leaves, the aerial parts or the flowering tops, is used to flavor various food products such as confectionery, baked goods, ice creams, puddings, liquors and non-alcoholic beverages. It may also be used as a flavoring for certain dental and oral hygiene products (1,31). In addition, *Ocimum basilicum* essential oils, notably those from the flowering tops, are widely used in the pharmaceutical, cosmetic, aromatherapy and perfumery industries (2,31,33). Basil oils are reported to possess a range of biological activities such as immunostimulant, hypnotic, local anesthetic, anticonvulsant, galactogogue, stomachic, antiviral, sedative, antitussive, diuretic, carminative, spasmodic, insect repellent, nematicidal, antibacterial, antifungal and antioxidant (3,21,31,33).

CHEMICAL COMPOSITION

Basil oil is a pale yellow to ambery yellow clear mobile liquid, which has a spicy, slightly anisic to spicy woody or to spicy cinnamic odor. The yield of essential oil from the flowering aerial tops of *Ocimum basilicum* L. generally varies from 0.01 to 0.3%. The main producing countries of this oil are India, Vietnam, France, Hungary, Egypt, Nepal, Indonesia, Morocco and USA.

Literature data (up to August 5, 2014) on the chemical composition of basil oils and unpublished analytical data from one of us (E.S.) are shown in Table 5.4.3 in alphabetical order. In basil oils from various origins, over 435 chemicals have been identified. About 53% of these were found in a single reviewed publication only.

The major compounds found in basil oils from different sources are shown in Table 5.4.4. They include (highest concentrations in any study given) linalool (98.9%), methyl chavicol (94.6%), methyl eugenol (91.1%), (*E*)-methyl cinnamate (82.4%), 1,8-cineole (54.3%), geranial (39.4%), neral (29.4%), eugenol (29.0%) and epi-α-cadinol (27.5%). Well-known ingredients of basil oils that were present in high concentrations (>15%) in one or two studies were (*E*)-anethole (74.6%), borneol (31.0% and 42.1%), (*Z*)-methyl cinnamate (38.2%), menthone (33.1%), β-bisabolene (25.6%), α-cadinol (21.1%) and α-farnesene (16.4%). Uncommon or rare constituents of basil oil found in high concentrations (>11%) in single studies include linalyl acetate (55.2%), elemene (39.1%), α-bergamotene (23.1%), (*E*)-myroxide (19.6%), α-linalool (16.0%) (adulteration), naphthalene (13.7%), α-cadinene (11.9%) and humulene (ep)oxide II (11.0%).

Table 5.4.1 ISO values (%) for basil oil, methyl chavicol type[a]

Compound	CAS	Minimum	Maximum
Methyl chavicol	140-67-0	75.0	87.0
1,8-Cineole	470-82-6	1.0	3.5
Linalool	78-70-6	0.5	3.0
(*E*)-β-Ocimene	3779-61-1	0.9	2.8
Methyl eugenol	93-15-2	0.3	2.5
Camphor	76-22-2	0.15	0.8
Terpinen-4-ol	562-74-3	0.2	0.6

[a] ISO 11043 Essential oil of basil, methyl chavicol type ©ISO 1998; Geneva, Switzerland, www.iso.org

Table 5.4.2 AFNOR values (%) for basil oil, linalool chemotype[a]

Compound	CAS	Minimum	Maximum
Linalool	78-70-6 4	5.0	62.0
Methyl chavicol	140-67-0	tr	30.0
Eugenol	97-53-0	2.0	15.0
1,8-Cineole	470-82-6	2.0	8.0
Terpinen-4-ol	562-74-3	tr	4.0
(*E*)-β-Ocimene	3779-61-1	0.2	2.0
Camphor	76-22-2	0.2	1.5

[a]AFNOR NF T 75-244 Huile essentielle de basilic, type linalol © AFNOR 1998; 11, rue de Francis de Pressensé, 93571 La Plaine Saint-Denis Cedex, France; www.afnor.org

Commercial oils

The ten chemicals that had the highest maximum concentrations in 47 commercial sweet basil essential oil samples (concentration ranges provided) are the following: methyl chavicol (0.2-87.0%), linalool (0.6-55.8%), methyl eugenol (0-24.7%), (*Z*)-methyl cinnamate (0-23.6%), *trans*-α-bergamotene (0.01-19.8%), eugenol (0.03-15.3%), 1,8-cineole (0.03-13.7%), τ-cadinol (0-7.1%), β-elemene (0-5.5%) and α-guaiene (0-4.3%) (Erich Schmidt, unpublished analytical data).

Chemotypes

There are several types of basil oil in international commerce, each derived principally from different cultivars or chemotypes of sweet basil. The oils of commerce are known as European (French or sweet basil), Egyptian, Reunion or Comoro, and tropical basil oils (2,3,21). The high-quality European type of basil oil from Italy, France, USA and South Africa characteristically contains linalool, methyl chavicol (estragole) and smaller quantities of 1,8-cineole, α-pinene, β-pinene, and myrcene. Egyptian basil oil of commerce is similar to the European oil, except that the concentration of linalool is significantly lower while the concentration of methyl chavicol is significantly higher. In contrast, Reunion or Comoro basil oils from Reunion, Comoros, Seychelles, Thailand, Madagascar and Vietnam contain little if any linalool and have a harsher, spicy aroma due to the very high concentration of methyl chavicol (2,3,5). The tropical oils from Java, India, Pakistan and Guatemala are rich in methyl cinnamate (3,5,21). There is also a eugenol-rich type of basil oil from North Africa and Russia, Eastern Europe, and parts of Asia (3,14,21).

Table 5.4.3 Constituents identified in basil oils

Constituent	CAS	Percentage and range						
		A	B (64)	C (2)	D (11)	E (3)	F (30)	G
Acetic acid	64-19-7							+^{z35}
α-Acoradiene	24048-44-0							tr^{f}; 0.05^{z15}
β-Acoradiene	28477-64-7			tr				tr^{f,l}; 0.07^{z15}; 0.2^{z4}
10-epi-β-Acoradiene	847374-86-1			0.1				
7-epi-Amiteol	147383-87-7					0.2		
α-Amorphene	20085-19-2		2.8					1.1^{z}; 1.6^{t}; 3.1^{j}; 4.1^{z2}; 4.8^{z32}
δ-Amorphene	189165-79-5							0.1^{f}; 0.3^{l,p}
(*E*)-Anethole	4180-23-8		0.5	tr				0.1^{z5}; 0.2^{z12}; 0.6^{z14}; 1.5^{v}; 74.6^{e}
(*Z*)-Anethole	25679-28-1			0.1				
p-Anisaldehyde	123-11-5		0.5	tr	0.1			0.07^{z19}; 0.2^{o}
Aromadendrene	489-39-4		4.3		0.7		0.2	tr^{f,l}; 0.09^{z7}; 0.2^{z2}; 0.3^{y}; 1.3^{z24}
allo-Aromadendrene	25246-27-9		0.2		0.1			0.2^{t}; 0.8^{r}
Azulene	275-51-4							0.7^{z9}
Benzaldehyde	100-52-7		0.3					<0.01^{z15}; 0.07^{z3}
Benzoic acid	65-85-0							+^{z35}
Benzyl alcohol	100-51-6							+^{z35}
Benzyl benzoate	120-51-4							+^{z35}
α-Bergamotene	17699-05-7		23.1					3.7^{k}; 4.1^{z10}; 5.7^{z23}; 8.0^{t}; 9.2^{s}
cis-α-Bergamotene	18252-46-5			tr				0.5^{r}; 1.1^{z5}; 5.8^{z24}; 10.0^{n}
trans-α-Bergamotene	13474-59-4	0.01-19.8		3.1	5.9		3.2	1.1^{z1}; 2.4^{p}; 3.4^{c}; 3.9^{z2}; 6.9^{r}; 7.5^{f}; 7.6^{e}; 14.9^{i}; 15.8^{z4}; 17.5^{v}
Bicycloelemene	32531-56-9							0.01^{z15}
Bicyclogermacrene	24703-35-3	0-1.2	0.9	1.0	0.9	2.0		1.7^{b}; 2.0^{u}; 3.1^{z24}; 4.0^{v}; 7.8^{z4}

Table 5.4.3 Constituents identified in basil oils (*continued*)

Constituent	CAS	Percentage and range						
		A	B (64)	C (2)	D (11)	E (3)	F (30)	G
epi-Bicyclophellandrene								7.4[z28]
epi-Bicyclosesquiphellandrene	54274-73-6						0.4	0.4[k]; 0.6[z9]
α-Bisabolene	17627-44-0		2.2			3.4	1.0	1.1[t]; 3.6[z8]
(*E*)-α-Bisabolene	25532-79-0	0,09-2.0		0.6				0.5[z1]; 0.9[b]; 9.5[n]
(*Z*)-α-Bisabolene	29837-07-8							0.1[o]; 0.7[v]; 0.8[p]; 10.1[z31]
β-Bisabolene	495-61-4		0.4	tr	25.6	0.3		0.1[k]; 0.3[z8]; 0.5[t]; 0.6[n]; 2.5[m]
γ-Bisabolene	495-62-5		0.2					
(*E*)-γ-Bisabolene	53585-13-0				3.9			
(*Z*)-γ-Bisabolene	13062-00-5							1.1[z28]
(*Z*)-δ-Bisabolene								1.1[y1]
α-Bisabolol	515-69-5			0.1				tr[f,l]; 0.3[z2]; 0.4[s]; 0.9[z4]
epi-α-Bisabolol	78148-59-1			0.1	0.3			
β-Bisabolol	15352-77-9				0.5	0.3		0.2[z4]
Borneol	507-70-0	0.03-0.2	0.9	0.4	1.4	0.9		0.7[f]; 1.9[x]; 2.1[k]; 3.7[h]; 60.1[z9]
Bornyl acetate	76-49-3	tr-4.2	4.9		1.2			1.1[p]; 1.2[z18]; 1.3[r]; 1.8[z3]; 2.0[d]
β-Bourbonene	5208-59-3			0.1	0.1	0.2		<0.1[t]; 0.2[n,w]; 0.4[z2]; 0.6[v]
Bulnesene	164108-17-2							1.5[z18,z20]
α-Bulnesene	3691-11-0		1.9	2.0			1.1	0.7[j]; 0.8[f]; 0.9[l]; 1.9[p,z4]; 2.3[z11]
Butanal	123-72-8							+[z35]
n-Butyric acid	107-92-6							+[z35]
Cadina-1,4-diene	29837-12-5		0.9					0.03[z7]; 0.2[t]; 1.0[k]
cis-Cadina-1(6),4-diene	1187195-00-1			0.5				
Cadina-3,5-diene	267665-20-3							0.1[z15]; 0.9[z4]
α-Cadinene	24406-05-1			tr	11.9			tr[l]; 0.3[v]; 0.4[c,r]; 1.9[o]
β-Cadinene	523-47-7		7.2					
γ-Cadinene	39029-41-9		3.1	2.5	0.7	5.0	2.5	3.5[z4]; 4.1[e]; 4.4[n]; 5.4[s]; 6.3[z2]
δ-Cadinene	483-76-1	0.01-0.9	0.3	0.1		8.7	0.7	2.1[z4]; 3.6[y]; 6.7[z14]; 7.7[z2]; 8.1[z10]
d-Cadinene	880143-55-5		2.2					
Cadinol	11070-72-7							6.9[h]
α-Cadinol	481-34-5		5.9	0.6	3.4	2.9		2.6[z4]; 2.9[z]; 6.5[p]; 6.8[t]; 21.1[z2]
epi-α-Cadinol	5937-11-1	0-7.1		9.3	1.8		8.3	5.7[l]; 6.2[z11]; 6.5[z24]; 6.7[f]; 7.1[z14] 7.6[c]; 12.4[s]; 17.3[n]; 27.5[z4]
γ-Cadinol	50895-55-1							3.7[e]
δ-Cadinol	19435-97-3							0.6[z11]
α-Calacorene	21391-99-1			tr				+[z33]
β-Calacorene	50277-34-4							+[z33]
cis-Calamene	72937-55-4							0.2[z]; 0.3[r]; 0.4[z24]; 1.1[z2]
trans-Calamene								0.5[f]
Calamenene	483-77-2					0.4		0.02[z3]; 0.2[z14,z20]; 0.8[c]; 1.0[s]
cis-Calamenene	72937-55-4		0.2					
trans-Calamenene	73209-42-4			0.5				0.3[z18]; 0.4[l]; 0.5[p,v]
Calarene	17334-55-3		1.8					<0.1[z4]
Camphene	79-92-5	tr-1.2		tr	0.4		0.3	0.2[g]; 0.4[h]; 0.5[w]; 0.8[c]; 4.7[z17]
Camphenol	3570-04-5						0.3	
E-Camphenone								0.2[y]
Camphor	76-22-2	0-2.1	3.9	0.7	9.1	3.2	1.4	3.4[d]; 4.3[m]; 4.5[h]; 31.0[x]; 42.1[z17]
δ2-Carene (=δ4-)	554-61-0				0.1			
δ3-Carene	13466-78-9							0.04[z12]; 0.08[n]; 0.7[z2]
Carvacrol	499-75-2		0.7	0.1	tr			0.7[z14]; 0.9[z9]; 1.8[n]; 2.7[e]
(*E*)-Carveol	1197-07-5							0.4[w]
Carvone	99-49-0			tr		0.5		0.2[w]; 0.4[z2]; 0.5[z5]; 1.6[z14]
Caryophyllene	87-44-5		2.0					
β-Caryophyllene	87-44-5	0.02-1.4	1.0	0.5	5.2	4.2	43.0	2.5[w]; 3.2[d]; 4.5[y]; 6.2[z31]; 7.1[x]; 7.5[v]; 8.0[i]; 10.7[z31]; 14.9[n]
Caryophyllene oxide	1139-30-6	0-0.2	0.5	0.1	1.1	2.0	13.9	1.1[b]; 2.5[z2]; 4.0[z9]; 8.0[n]; 11.4[w]
Caryophyllenol	38284-26-3							0.3[y]
Cedrene	11028-42-5							tr[f]

Table 5.4.3 Constituents identified in basil oils (*continued*)

Constituent	CAS	Percentage and range						
		A	B (64)	C (2)	D (11)	E (3)	F (30)	G
α-Cedrene	469-61-4							0.3[z2]
β-Cedrene	546-28-1			tr				tr[l]; 2.9[z2]
Chavicol	501-92-8		1.1					0.02[z7]; 0.1[z]; 0.3[t]; 0.8[o]; 1.0[z2]
trans-Chrysanthemal	20104-05-6							2.5[b]
trans-Chrysanthenol	38043-83-3							1.4[z1]
Chrysanthenyl acetate								0.3[z6]
1,4-Cineole	470-67-7						0.2	
1,8-Cineole	470-82-6	0.03-13.7	12.1	8.1	17.5	14.5	14.6	9.8[d]; 10.1[v]; 12.9[c]; 13.7[z13]; 14.8[m]; 15.3[h]; 16.5[r]; 54.3[w]
Cinnamyl acetate	103-54-8							1.2[z3]
(*E*)-Cinnamyl acetate	21040-45-9							0.09[z20]
Citral	5392-40-5					65.6		0.6[g]
Citronellal	106-23-0							1.6[o]
Citronellol (β-, DL-)	106-22-9				0.4	0.2		0.2[g]
Citronellyl acetate	150-84-5				0.6			
α-Copaene	3856-25-5	0-0.6	0.7	0.1	1.9	0.6	0.4	0.6[z2]; 0.9[n]; 1.4[z26]; 1.5[v]; 7.5[w]
β-Copaene	18252-44-3			tr	0.5			0.09[z15]
Coumarin	91-64-5							+[z35]
α-Cubebene	17699-14-8		0.1	tr	0.4	1.6	0.1	0.1[t,z]; 0.3[z14]; 0.4[o]; 0.8[w]; 6.2[z15]
β-Cubebene	13744-15-5		1.1	tr	0.1	0.5		0.6[x]; 0.9[n]; 1.1[t]; 1.8[w]; 2.3[m]
10-epi-Cubebol	176589-53-0							tr[l]
Cubenol	21284-22-0							0.7[j,z5]; 0.8[r,z11,z24]
1-epi-Cubenol	81939-29-9						1.9	tr[l]
1,10-di-epi-Cubenol	73365-77-2			1.3				0.3[z19]; 0.7[l]; 0.8[f,p,z18]; 4.2[z4]
Cuminaldehyde	122-03-2							+[z35]
β-Curcumene	28976-67-2			tr				
Cyclobazzanene	88661-61-4							0.03[z12]
1,6-Cyclodecadiene	1124-79-4							0.6[z9]
Cyclohexane	110-82-7							2.1[z9]
Cyclohexanol	108-93-0							0.4[k]
Cyclohexene	110-83-8							0.5[k]
p-Cymene	99-87-6		0.7	0.1	0.2		0.4	0.2[n]; 0.6[v]; 0.9[e]; 1.1[j]; 1.2[w]; 1.3[x]
p-Cymenene	1195-32-0	0-0.3						
p-Cymen-4-ol			0.1					
p-Cymen-8-ol	1197-01-9			tr				0.2[o]
β-Damascenone (*E*)-	23726-93-4		0.1	tr				0.2[z14]
β-Damascone	23726-91-2							+[z35]
2,4-Decadienal	2363-88-4							+[z35]
Decanal	112-31-2							0.7[r]
n-Decane	124-18-5			tr				tr[z34]
n-Decanoic acid	334-48-5							+[z35]
Decanol	36729-58-5							+[z35]
2,3-Dehydro-1,8-cineole	92760-25-3			tr				
Dibutyl octanedioate	16090-77-0							<0.01[z7]
Dihydroanethole	104-45-0			tr				0.2[y1]
Dihydroedulan II	41678-32-4							0.4[y]
Dill ether	74410-10-9					0.2		
2,6-Dimethyl-1-hep- tanol	2768-12-9							0.3[y]; 1.0[n]
(*E*)-2,6-Dimethyl-3,7-octadien-2,6-diol	13741-21-4			0.1				
3,7-Dimethyl-1,5-octadien-3,7-diol	13741-21-4							0.3[z15]
3,7-Dimethyl-1,7-octadiene-3,6-diol								0.03[z15]
Docosane	629-97-0							<0.1[y1]
1-Docosene	1599-67-3							tr[z28,y1]
δ-Dodecalactone	713-95-1							+[z35]
Dodecanol	112-53-8							+[z35]
3-Dodecanone	1534-27-6							0.2[y]
Eicosane	112-95-8							<0.1[y1]; 0.2[y];
(*E*)-1-Eicosene	3452-07-1							0.2[y]

Table 5.4.3 Constituents identified in basil oils (*continued*)

Constituent	**CAS**	**Percentage and range**						
		A	**B (64)**	**C (2)**	**D (11)**	**E (3)**	**F (30)**	**G**
Elemene	11029-06-4							39.1[h]
β-Elemene	33880-83-0	0-5.5	2.5	2.0	0.8	1.6		2.7[f]; 3.2[p]; 3.5[v]; 3.6[b]; 8.2[z14]
γ-Elemene	29873-99-2		0.2					0.6[z8]; 1.1[z9]; 1.9[z14]; 10.9[m]
δ-Elemene	20307-84-0							tr[c,l]
Elemol	639-99-6						0.5	0.1[o]; 0.3[z2]; 2.1[z16]; 2.9[z6]
Elixene	3242-08-8							0.05[z7]; 0.3[z11]
Epizonarene	41702-63-0							0.5[k]
(*E*)-Epoxyocimene	255832-06-5		0.3					
(*Z*)-Epoxyocimene								0.4[z24]
Eremophilene	10219-75-7							+[z33]
2-Ethylfuran	3208-16-0							+[z35]: 0.02[z14]
Ethyl isovalerate	108-64-5				0.7			
Ethyl-2-methyl butyrate	7452-79-1							+[z35]
Eudesma-4(15),7-dien-1β-ol	119120-23-9			0.1				
α-Eudesmol	473-16-5							0.1[z16]; 0.2[z6]; 4.7[z1]; 7.1[b]
β-Eudesmol	473-15-4			0.3	2.5	0.7		0.3[s]; 0.4[z5]; 0.6[q]; 1.1[z2]; 5.7[r]
γ-Eudesmol	1209-71-8				1.9			0.2[z6]; 0.4[z16]
10-epi-γ-Eudesmol	15051-81-7							0.1[t]
Eugenol	97-53-0	0.03-15.3	20.1	2.4	5.9	21.1	4.1	8.7[h]; 11.1[z4]; 12.3[z18]; 13.5[z21]; 14.2[i]; 24.8[j]; 27.6[p]; 29.0[d]
Eugenyl acetate	93-28-7							+[z35]; 0.3[z20]
α-Farnesene	502-61-4		16.4					0.9[c]; 2.0[m]; 5.5[j]
(*E,E*)-α-Farnesene	502-61-4				0.3			
(*Z,E*)-α-Farnesene	26560-14-5			tr				
β-Farnesene	502-60-3		1.8					0.3[t]; 1.4[z9]
(*E*)-β-Farnesene	18794-84-8	0.05-4.1		0.1	1.9	1.1	0.7	0.4[k]; 0.7[b]; 1.1[z]; 3.9[z2]; 4.1[v]
(*Z*)-β-Farnesene	28973-97-9			tr	0.1			0.2[y]; 1.0[r]; 1.3[f]; 1.6[n]; 1.7[j]; 2.9[p]
Farnesol	4602-84-0							0.2[b,k]
(*E,E*)-Farnesol	106-28-5							0.1[y]
Farnesyl acetate	29548-30-9							0.1[z4]
endo-Fenchol (α-)	512-13-0		0.6	tr				tr[l,z33]
exo-Fenchol (β-)	22627-95-8			tr				
Fenchone	1195-79-5	0-0.7	2.1	0.1		0.5	0.9	1.9[j]; 2.6[n]; 3.1[z9]; 7.0[v]; 10.1[z12]
Fenchyl acetate	13851-11-1	0-0.6	3.0			0.1	0.3	tr[l]; 0.6[c]; 1.8[f]
α-Fenchyl acetate (endo-)	111821-74-0							0.04[z15]; 0.4[j]; 0.6[z12,z13]
β-Fenchyl acetate (exo-)	76109-40-5							1.2[z12]
Fenchyl alcohol	1632-73-1	0-0.3	1.7					0.3[c,z8]
Furfural	98-01-1			tr				
Geranial	141-27-5	0-0.6	0.7	0.2	36.9			1.6[j]; 24.6[n]; 25.7[z31]; 39.4[o]
Geraniol	106-24-1		0.9	5.1	6.8	3.9		0.1[b,g]; 0.3[q]; 1.5[j]; 1.7[z10]; 2.1[n] 4.3[p]; 5.2[o]; 12.5[v]; 13.4[f]; 16.5[l]
(*E*)-Geraniol	106-24-1						1.1	
(*Z*)-Geraniol	106-25-2						0.2	1.3[s]
Geranoic acid	459-80-3							+[z35]
Geranyl acetate	105-87-3		0.4	0.1	0.2			0.5[r]; 0.7[f,n]; 1.4[z6]; 1.7[l]; 4.0[z16]
Geranyl acetone	3796-70-1			tr				
(*Z*)-Geranylacetone	3879-26-3							0.1[z14]
Geranyl formate	105-86-2				0.2			0.5[e]
Germacrene	28028-64-0							5.7[z10]
Germacrene A	28387-44-2							0.6[e]; 1.2[z14]; 1.4[z26]; 2.3[k]; 3.2[h]
Germacrene B	15423-57-1						1,4	0.3[p]; 0.9[b]; 1.0[k]; 1.3[c]
Germacrene D	23986-74-5	0.01-3.6	1.7	3.0	2.6	4.3		4.1[p]; 4.4[h]; 5.7[z24]; 6.0[v]; 8.7[n]
Globulol	489-41-8							tr[l]; 0.2[z17]
α-Guaiene	3691-12-1	0-4.3		0.6			0.7	1.0[p]; 1.1[k]; 1.4[f]; 2.1[z1]; 2.6[b]; 2.9[n]
β-Guaiene	88-84-6		2.9			1.7		
trans-β-Guaiene	192053-49-9							2.5[v]
γ-Guaiene	145267-53-4							0.8[z13]; 2.1[z24]; 4.3[z14]
Guaiol	489-86-1				0.1			
Guaiyl acetate	134-28-1							3.0[k]

Table 5.4.3 Constituents identified in basil oils (*continued*)

Constituent	CAS	Percentage and range						
		A	B (64)	C (2)	D (11)	E (3)	F (30)	G
α-Gurjunene	489-40-7			tr	0.1			tr[z16]; 0.2[z5]; 0.3[o]
β-Gurjunene	73464-47-8							<0.1[t]; 0.1[o]; 0.6[n]; 1.4[z17]
γ-Gurjunene	22567-17-5							+[z35]
Heneicosane	629-94-7							<0.1[y1]
Hentriacontane	630-04-6							tr[y1]
Heptadecane	629-78-7			tr				
(*E,E*)-2,4-Heptadienal	4313-03-5			tr				
Heptanal	111-71-7							+[z35]
Heptanoic acid	111-14-8							+[z35]
n-Hexadecane	544-76-3			tr				
Hexadecanoic acid	57-10-3		0.6			0.7		
1-Hexadecene	629-73-2			tr				tr[z28]
Hexahydrofarnesyl acetone	502-69-2			0.1				0.4[z14]
Hexanal	66-25-1							0.03[z14]
Hexanoic acid	142-62-1							+[z35]
1-Hexanol (*n*-)	111-27-3			tr	tr			<0.01[z7]
(*E*)-3-Hexenol	928-97-2							0.4[o]
(*Z*)-3-Hexen-1-ol	928-96-1	0-0.04		0.1	0.1			0.05[z3]; 0.06[z7]
(*E*)-3-Hexenyl acetate	3681-82-1			tr				0.2[o]
(*Z*)-3-Hexenyl acetate	3681-71-8	0-0.06			0.2			<0.01[z15]; 0.01[z14]; 0.1[z17]
(*Z*)-3-Hexenyl angelate	84060-80-0			tr				
(*Z*)-3-Hexenyl benzoate	25152-85-6							+[z35]
(*Z*)-2-Hexenyl butyrate								0.07[z14]
(*Z*)-3-Hexenyl (*Z*)-3-hexenoate	61444-38-0			tr	0.2			
(*Z*)-3-Hexenyloxy-acetaldehyde	68133-72-2			tr				
α-Himachalene	3853-83-6							0.2[z2]
Himachalol	1891-45-8							tr[f]
(*E*)-Hotrienol	53834-70-1			0.3				
α-Humulene	6753-98-6	0.04-1.2	2.6	0.7	2.7	1.6		2.9[z4]; 3.0[v]; 3.2[z26]; 6.3[w]; 13.6[n]
β-Humulene	116-04-1							1.8[z20]
α-Humulene (ep)oxide	96638-51-6					0.5		0.9[z2]; 2.0[b]
Humulene (ep)oxide I	19888-33-6			0.2				0.1[o]
Humulene (ep)oxide II	19888-34-7				0.2			0.08[z19]; 0.1[z4]; 0.7[z1]; 11.0[w]
exo-2-Hydroxycine-ole acetate	72257-53-5							0.05[z15]
Intermedeol	6168-59-8							tr[l]; 0.5[z4]
(*E*)-β-Ionone	79-77-6					0.2		0.1[z]; 0.2[z14]; 1.0[z2]
Isoamyl acetate	123-92-2				tr			
Isoamyl alcohol	123-51-3							+[z35]
Isoamyl isovalerate	659-70-1							0.07[z12]
Isoborneol	124-76-5							0.3[z17]
Isobornyl acetate	125-12-2			1.3	1.5		0.6	
(*Z*)-Isocitral	72203-97-5							0.9[o]
Isoeugenol	97-54-1		10.6					
trans-Isolimonene	6876-12-6							2.0[y]
Isolongifolene	1135-66-6							0.4[k]
Isomenthone	491-07-6	0-1.9		tr				tr[z34]; 0.3[z27]
Isoneomenthol								0.4[z2]; 7.5[z]
Isopulegol acetate	57576-09-7							0.3[z]
Isospathulenol	88395-46-4		0.9					
Isoterpinolene	586-63-0						1.5	
Isovaleric acid	503-74-2							+[z35]
(*E*)-Jasmone	6261-18-3							+[z35]
(*Z*)-Jasmone	488-10-8							0.2[z16]
Lauric acid	143-07-7							+[z35]
Lavandulyl acetate	25905-14-0							0.3[z6]; 0.8[z16]
Ledol	577-27-5							+[z35]; 0.2[y]
Lilac aldehyde A	53447-46-4			0.1				

Table 5.4.3 Constituents identified in basil oils (*continued*)

Constituent	CAS	Percentage and range						
		A	B (64)	C (2)	D (11)	E (3)	F (30)	G
Limonenal	6784-13-0						0.4	
Limonene	138-86-3	0.03-1.1	0.6	0.1	0.8	0.4	3.6	2.3[w]; 4.7[x]; 6.2[e]; 7.6[z17]; 10.4[z21]
cis-Limonene oxide	13837-75-7							0.2[w]
α-Linaloool	598-07-2			16.0[a]				
Linalool	78-70-6	0.6-55.8	66.4	79.5	74.3	60.2	33.0	67.9[i]; 73.2[d]; 74.0[l]; 74.5[m]; 75.9[f]; 77.5[p]; 83.6[z23]; 98.9[x]
Linalool oxide	1365-19-1							1.1[s]
cis-Linalool oxide	11063-77-7		1.7				0.3	tr[l]; 0.08[z3]; 0.3[z19]; 0.4[b,f]
cis-Linalool oxide, furanoid	11063-77-7			0.7	tr			0.1[z1]
cis-Linalool oxide, pyranoid	14009-71-3			tr				
trans-Linalool oxide	11063-78-8		1.6					0.08[z3]; 0.1[y]; 0.2[b,u]; 0.3[f,t]
trans-Linalool oxide, furanoid	34995-77-2			0.7	0.2			
Linalyl acetate	115-95-7				0.5	0.6		0.2[z14]; 0.5[s]; 14.0[z16]; 55.2[z6]
Linalyl formate	115-99-1							0.9[k]
Linalyl propionate	144-39-8					2.4		1.7[h]
Longipinanol	66141-14-8							tr[l]
γ-Maaliene	20071-49-2							0.2[z17]
Maaliol	527-90-2			0.3				
p-Mentha-2,4(8)-diene	586-63-0							0.2[z6]
p-Menthene	5502-88-5							0.3[z27]
p-Menth-2-en-1-ol	619-62-5							<0.01[z15]; 0.5[c]
cis-*p*-Menth-2-en-1-ol	29803-82-5							0.2[t]; 0.6[o]
trans-*p*-Menth-2-en-1-ol	29803-81-4							0.5[o]
Menthofuran	494-90-6							0.1[y]
Menthol	89-78-1	0-0.7		0.1				0.6[n]; 6.1[z]
Menthone	89-80-5	0-0.3		0.1				0.3[z34]; 0.6[y]; 1.2[z2]; 33.1[z]
Menthyl acetate	16409-45-3							tr[z34]; 5.6[z]
p-Methoxyacetophenone	100-06-1			tr				+[z35]
p-Methoxybenzoic acid	100-09-4							+[z35]
3-Methoxycinnamaldehyde	56578-36-0							0.2[z1]; 0.3[b]
o-Methoxycinnamaldehyde (2-)	1504-74-1							0.3[n]
(*E*)-*p*-Methoxycinnamaldehyde	24680-50-0			0.1				
2-Methoxycinnamic alcohol		0-0.5						
2-Methoxy-3-methylpyrazine	2847-30-5							+[z35]
3-Methylbutanal	590-86-3							0.05[z14]
2-Methylbutanoic acid	116-53-0				0.1			+[z35]
Methylcarvacrol	6379-73-3			tr				
Methyl chavicol	140-67-0	0.2-87.0	87.8	22.8	88.2	76.3	12.3	71.5[d]; 85.5[e]; 87.2[g]; 87.8[m]; 89.9[i]; 90.0[o]; 94.3[q]; 94.6[t]
Methyl cinnamate	103-26-4					63.1		11.2[g]; 21.6[z20]; 59.3[z25]
(*E*)-Methyl cinnamate	1754-62-7		7.4		38.7		74.5	16.7[z14]; 31.9[z3]; 41.9[z31]; 82.4[m]
(*Z*)-Methyl cinnamate	19713-73-6	0-23.6	38.2		6.1		9.8	0.1[t]; 0.4[p]; 0.6[b]; 4.7[z3]; 5.9[m]
2-Methyldecane	6975-98-0			tr				
Methyl eugenol	93-15-2	0-24.7	38.8	0.2	14.9	34.2	26.0	0.8[p]; 2.0[n]; 2.3[f]; 2.5[m]; 5.6[r] 40.5[j]; 74.5[e]; 78.0[z15]; 91.1[d]
Methylfuran	27137-41-3					0.5		+[z35]
Methylheptenone	409-02-9	0-0.1						
6-Methyl-3-heptenone						1.3		
6-Methyl-5-hepten-2-one	110-93-0			tr	0.5			tr[o]; 0.3[b,z1]; 1.6[v]

Table 5.4.3 Constituents identified in basil oils (*continued*)

Constituent	**CAS**	**Percentage and range**						
		A	**B (64)**	**C (2)**	**D (11)**	**E (3)**	**F (30)**	**G**
Methyl isoeugenol	93-16-3							2.2^{z29}
(*E*)-Methylisoeugenol	6379-72-2							0.5^{z9}
Methyl isovalerate	556-24-1							+^{z35}
Methyl jasmine						0.4		
Methyl jasmonate	1211-29-6							+^{z35}
Methyl epi-jasmonate	42536-97-0							+^{z35}
Methyl 2-methylbu-tyrate	868-57-5							+^{z35}
Methyl salicylate	119-36-8							+^{z35}
Methyl thymol	1076-56-8			tr				
Mintsulfide	72445-42-2							0.01^{z27}
cis-Muurola-3,5-diene	157374-44-2			0.2				tr^{f}; 0.4^{p}; 0.5^{l}
cis-Muurola-4(14),5-diene	157477-72-0							0.1^{z15}; 0.6^{f,l}; 0.7^{p}; 1.3^{z4}
trans-Muurola-4(14), 5-diene	262352-87-4			tr				
α-Muurolene	10208-80-7	0-1.1		tr				tr^{q}; 0.1^{o,z2}; 0.3^{z7}; 0.9^{e}; 1.1^{z13}
γ-Muurolene	30021-74-0			tr	0.9			0.2^{z11}; 0.4^{c}; 0.6^{u}; 0.9^{o,s}; 2.2^{r}
ε-Muurolene	30021-46-6							0.7^{z15}
τ-Muurolene	152287-43-9							0.2^{b}
cis-14-nor-Muurol-5-en-4-one				tr				
α-Muurolol	104245-48-9			0.1	0.1			
τ-Muurolol (epi-α-)	19912-62-0							0.2^{z1}
Myrcene	123-35-3	0.02-2.9	1.0	0.5	1.1	0.9	1.4	2.0^{g}; 2.9^{r}; 3.3^{z6}; 3.6^{z9}; 5.6^{z16}
Myristic acid	544-63-8							+^{z35}
(*E*)-Myroxide	28977-57-3							<0.01^{z15}; 19.6^{w}
(*Z*)-Myroxide	33281-83-3						0.3	tr^{f,l}; 0.1^{z19}
Myrtenal	564-94-3							<0.1^{x}; 0.1^{z17}
Myrtenol	515-00-4							<0.1^{x}; 3.3^{z17}
Myrtenyl acetate	1079-01-2							0.2^{z16,z17}
Naphthalene	91-20-3			tr				0.7^{z9}; 13.7^{k}
Neointermedeol	5945-72-2							tr^{l}
Neomenthol	3623-51-6			0.1				
Neophytadiene	504-96-1							0.2^{k}
Neral	106-26-3	0.08-0.5		0.1	27.6			10.0^{v}; 20.8^{z31}; 22.7^{n}; 29.4^{o}
Neranoic acid								+^{z35}
Neric acid	37349-29-4							+^{z35}
Nerol	106-25-2		0.4	0.1	9.7	1.8		0.9^{z16}; 2.7^{n}; 11.2^{o}; 12.6^{z24}
Nerolidol	7212-44-4		0.8			0.7	0.6	0.4^{z2}; 0.5^{j,z14}
(*E*)-Nerolidol	40716-66-3			0.2	0.4			0.4^{z4,z5}; 1.6^{z1}; 2.4^{b}
(*Z*)-Nerolidol	3790-78-1							0.7^{z18,z20}
Neryl acetate	141-12-8		0.2	tr	0.7	0.3		0.3^{z14}; 0.7^{o}; 0.9^{z6}; 2.4^{z16}
Nonacosane	630-03-5							tr^{z28,y1}
Nonadecane	629-92-5							<0.1^{y1}
Nonadecene	27400-77-7							0.1^{y}
β-Ocimene	13877-91-3		0.3					3.5^{z11}; 10.5^{z9}
(*E*)-β-Ocimene	3779-61-1	0.02-2.7	0.5	1.4	3.5			2.3^{z26}; 2.8^{p}; 3.0^{j}; 3.4^{q}; 3.9^{n}
(*Z*)-β-Ocimene	3338-55-4	tr-1.8		tr	0.8	2.0		1.8^{z26}; 2.0^{z6}; 2.1^{b}; 2.2^{z7}; 3.2^{e}
(*E*)-Ocimene	27400-72-2						2.4	1.0^{c}
(*Z*)-Ocimene	27400-71-1						0.5	tr^{c}
allo-Ocimene	673-84-7							0.07^{z18}; 0.1^{y}; 2.4^{z16}
neo-allo-Ocimene	7216-56-0		0.2					<0.01^{z15}; 0.2^{t}; 0.3^{z16}; 3.0^{z6}
Octadecane	593-45-3							0.3^{y1}
1-Octadecene	112-88-9			tr				tr^{z28}
2,4-Octadienal	30361-28-5							+^{z35}
Octanal	124-13-0							+^{z35}
n-Octane	111-65-9`			tr				
Octanoic acid	124-07-2							+^{z35}
1-Octanol (*n*-)	111-87-5			tr		0.2		0.04^{z14}; 0.1^{z5}
3-Octanol	589-98-0			0.1	tr			tr^{w}; 0.03^{z7}; 0.1^{z}; 0.7^{z2}
3-Octanone	106-68-3				tr			

Table 5.4.3 Constituents identified in basil oils (*continued*)

Constituent	CAS	Percentage and range						
		A	B (64)	C (2)	D (11)	E (3)	F (30)	G
Octan-3-yl acetate	103-09-3							0.2^{z16}; 0.3^{z6}
trans-Oct-2-en-1-al	2548-87-0							$+^{z35}$
1-Octen-3-ol	3391-86-4	0-0.06	0.2	0.4	0.2			0.3^{z5}; 1.0^{w}; 1.2^{n}; 1.4^{z17}
3-Octenol	18185-81-4							0.1^{y}
7-Octen-4-ol	53907-72-5							0.2^{y1}
Octenyl acetate	37366-04-4							0.03^{z14}
1-Octen-3-yl acetate	2442-10-6			0.1	0.3			0.07^{z18}; 0.1^{z16}; 0.2^{z6}
Octyl acetate	112-14-1	0-0.2	0.4	0.1			0.2	0.02^{z15}; 0.05^{z3}; 0.2^{z14}; 0.4^{k}
Palustrol	5986-49-2							0.3^{w}
Pentadecane	629-62-9			tr				
2-Pentylfuran	3777-69-3			tr				
Perillaldehyde	2111-75-3							$+^{z35}$
Phellandrene	1329-99-3					0.2		
α-Phellandrene	99-83-2				0.2			0.2^{z2}; 0.4^{z17}; 0.6^{n}; 2.2^{x}; 4.4^{z12}
α-Phellandrene-8-ol	1686-20-0						0.5	
β-Phellandrene	555-10-2							0.06^{z7}; 0.1^{z5}; 0.6^{z17}; 1.2^{z22}
Phenethyl alcohol	60-12-8							$+^{z35}$
Phenylacetaldehyde	122-78-1			tr				
Phenylethyl acetate	93-92-5							$+^{z35}$
Phytol	7541-49-3							0.1^{z}
trans-Pinane (*E*-)	10281-53-5							0.2^{y}
α-Pinene	80-56-8	0.02-2.7	0.3	0.1	0.5		0.9	0.9^{h}; 1.2^{v}; 1.7^{m}; 4.4^{x}; 5.4^{z17}
β-Pinene	127-91-3	0.04-2.1	0.7	0.4	1.4	1.2	1.6	1.3^{j}; 1.9^{m}; 2.0^{c}; 2.3^{h}; 8.2^{w}
trans-Pinocamphone	547-60-4			tr				
Pinocarvone	30460-92-5							tr^{l}; $<0.01^{z15}$; 0.9^{r}
cis-Piperitol	16721-38-3							0.7^{z30}
trans-Piperitol	16721-39-4							0.1^{z30}
Piperitone	89-81-6	0-0.06						0.3^{z}
Plinol	72402-00-7			tr				
Plinol C	4028-60-8			tr				
Propanoic acid	79-09-4							$+^{z35}$
Pulegone	89-82-7							$0.1^{y,z2}$; 0.3^{n}; 3.7^{z}
Quinoline	91-22-5							$+^{z35}$
Rosefuran epoxide	92356-06-4							6.0^{w}
cis-Rose oxide	3033-23-6							$0.2^{z,z2}$
Sabinene	3387-41-5	0.01-1.2	0.7	0.2	0.2	0.4	0.7	$0.4^{c,j}$; 0.5^{v}; 0.6^{e}; 1.0^{x}; 1.8^{r}
Sabinene hydrate	546-79-2							0.07^{n}
cis-Sabinene hydrate	15537-55-0			0.1	1.2		0.8	0.1^{o}; $0.3^{l,z17}$; 0.6^{p}; 0.9^{z26}; 1.9^{w}
trans-Sabinene hydrate	17699-16-0		0.5		tr	0.3		tr^{w}; $0.2^{r,z17}$; 0.9^{z26}
Salicylic acid	69-72-7							$+^{z35}$
Salvial-4(14)-en-1-one	73809-82-2			tr				
α-Santalene	512-61-8						0.3	0.4^{z20}
β-Santalene	511-59-1						0.8	
cis-β-Santalene								0.1^{z20}
α-Selinene	473-13-2			tr	1.5		0.7	0.8^{o}; 1.0^{z10}; 2.1^{r}; 3.6^{w}; 4.3^{z17}
β-Selinene	17066-67-0			0.2	4.4	2.8	1.1	1.7^{w}; 2.1^{z20}; 3.6^{z10}; 5.6^{z17}
Selin-11-en-4-ol	16641-47-7			1.3				
β-Sesquiphellandrene	20307-83-9				0.3	0.4	0.1	0.2^{p}; 2.6^{z4}
Sesquisabinene B	1367879-38-6			tr				
7-epi-Sesquithujene	159407-35-9			tr				
β-Sinensal (*cis*-)	17909-87-4							1.0^{b}
Spathulenol	6750-60-3		1.6	0.6	0.7	0.4	1.2	0.6^{y}; 1.6^{m}; 1.7^{z14}; 2.9^{z2}; 4.1^{n}
α-Terpinene	99-86-5			tr	0.1	0.2	0.3	tr^{f}; 0.05^{c}; 0.09^{n}; $0.2^{g,t}$; 0.3^{j}
γ-Terpinene	99-85-4		0.4	tr	1.9		0.9	0.4^{p}; 0.5^{x}; 0.9^{j}; 1.5^{z2}; 1.9^{k}
Terpinen-4-ol	562-74-3	tr-1.4	8.0	0.3	4.8	0.8	6.4	3.1^{c}; 3.5^{z21}; 5.3^{i}; 6.6^{o}; 9.0^{x}
1-Terpineol	586-82-3							$<0.01^{z3}$
α-Terpineol	98-55-5	0.04-1.7	2.1	1.0	1.0		2.6	1.4^{z13}; 2.4^{j}; 2.5^{o}; 5.1^{z16}; 6.6^{w}
γ-Terpineol	586-81-2							2.6^{m}

Table 5.4.3 Constituents identified in basil oils (*continued*)

Constituent	CAS	Percentage and range						
		A	B (64)	C (2)	D (11)	E (3)	F (30)	G
δ-Terpineol	7299-42-5	0-0.2		tr	0.3			tr[f,l]; 0.1[z4]; 0.2[z19]; 0.5[r]
Terpinolene	586-62-9	0-0.2	2.0	0.2	0.5	0.2		0.06[r]; 0.4[p]; 0.5[j]; 1.1[z17]; 1.5[c,e]
Terpinyl acetate	8007-35-0							0.9[k]
α-Terpinyl acetate	80-26-2			tr			0.8	tr[z16]; 0.1[z4]; 0.7[n]
Tetradecane	629-59-4			tr				
Tetradecene	26952-13-6			tr				
Tetramethylpyrazine	1124-11-4							+[z35]
β-Thujaplicine	499-44-5							0.3[y1,y2]
α-Thujene	2867-05-2			tr	tr			0.2[j,n]; 0.3[w,z21]; 0.4[z26]; 0.5[r]
α-Thujone	546-80-5		0.1					0.4[t]; 0.5[y]
Thymol	89-83-8		0.3	tr				+[z35]; 0.1[z14]; 0.3[n]; 0.5[e]
Thymyl acetate	528-79-0							0.4[z2]
Torreyol	19435-97-3							<0.1[z20]
n-Triacontane	638-68-6							tr[z28]
Tricosane	638-67-5							<0.1[y1]
Tricyclene	508-32-7							0.1[z17]
Tritriacontane	630-05-7							tr[z28,y1]
Undecane	1120-21-4		tr					
(9*Z*)-Undecen-1-al					0.1			
Valencene	4630-07-3							0.5[k]
Valeric acid	109-52-4							+[z35]
Vanillin	121-33-5							+[z35]
Verbenol	473-67-6							0.5[r]
trans-Verbenol	1820-09-3							0.8[v]
Viridiflorene (ledene)	21747-46-6							0.1[p]; 0.4[f]
Viridiflorol	552-02-3		0.5					0.07[n]; 0.1[y]; 0.4[z6]; 0.5[z16]; 1.8[s]
α-Ylangene	14912-44-8							0.02[z15]; 0.2[k]
α-Zingiberene	495-60-3		2.7			3.3		0.4[e]

A forty-seven basil essential oil samples from Egypt, India, France, Hungary, Morocco, Nepal and Vietnam, analyzed between 1998 and 2013; lowest and highest concentrations given (E. Schmidt, unpublished data)

B twenty-seven lab-hydrodistilled oils from the flowers and leaves of 27 cultivars of *O. basilicum* L. grown in Croatia; highest concentrations given (ref. 64); all chemicals were absent in one or more oil samples and therefore their lower concentration was zero; 1,8-cineole was found in all but one oil and the range in the other 26 was 0.4-12.1; linalool was present in all but two oils and its range in the other 25 oils was 1.7-66.4 (ref. 64)

C fifteen lab-hydrodistilled oils from the aerial parts of *O. basilicum* in the flowering stage, nine from the wild in Serbia and six obtained from two local pharmacies, plus three commercial oils from Serbia adulterated with α-linalool; mean values were presented for the wild group, both pharmacies groups separately and the commercial oils; highest mean values given (ref. 2); all oils were of the linalool chemotype

D fifteen lab-hydrodistilled oils from the aerial parts in bloom of basil plants growing wild in the foot- and mid-hills of northern India; highest concentrations given (ref. 11); most chemicals were absent in one or more oils and therefore their lower concentration was zero; the following components were found in all oils (range in brackets): myrcene (<0.05-0.7), 1,8-cineole (<0.05-17.5), linalool (0.1-74.3) and β-caryophyllene (tr-6.2) (ref. 11)

E eighteen lab-hydrodistilled oils from the aerial parts with flowers of *O. basilicum* cultivated in Turkey from eighteen Turkish landraces; highest concentrations given (ref. 3); most chemicals were absent in one or more oil samples and therefore their lower concentration was zero; the following components were found in all (but one, in the case of 1,8-cineole) oils (range in brackets): 1,8-cineole (<0.1-14.5), linalool 1.7-60.2), zingiberene (0.9-3.3), β-selinene (<0.1-2.8), germacrene D (0.7-4.3), γ-cadinene (0.4-5.0) and hexadecanoic acid (tr-0.7) (ref. 3)

F twelve lab-hydrodistilled oils from the whole flowering plant of 12 basil cultivars grown in Colombia; highest concentrations given (ref. 30); most chemicals were absent in one or more oils and therefore their lower concentration was zero; the following components were found in all oil samples (range in brackets): 1,8-cineole (0.3-14.6), linalool (0.9-33.0), methyl chavicol (0.5-12.3), (*Z*)-methylcinnamate (0.4-9.7) and (*E*)-methyl cinnamate (8.3-74.5) (ref. 30)

G data from other studies (indicated with superscript letters); highest concentrations found in any study reviewed here given; when two or more oils were investigated, only the highest concentrations are mentioned, unless indicated otherwise

Table 5.4.3 Constituents identified in basil oils (*continued*)

[a] adulteration of commercial oils with α-linaloool; [b] twelve lab-hydrodistilled oils from the aerial parts in the flowering stage of 12 accessions of *O. basilicum* var. *purpurascens* cultivated in Iran (ref. 52); [c] ten lab-hydrodistilled oils from the whole plant at the beginning of flowering of ten basil cultivars grown in Italy (ref. 7); [d] thirty-eight lab-hydrodistilled oils from 38 *O. basilicum* accessions of various genotypes in full bloom, cultivated in Mississippi, USA (ref. 5); only 10 components were investigated; [e] five lab-hydrodistilled oils from the leaves and inflorescences of wild growing basil collected at five localities in Togo (ref. 32); [f] eight essential oils from the whole over-ground part above the lignified parts of the sprout of four basil cultivars from Poland in full bloom with two regimes of nitrogen application to the leaves (ref. 19); [g] five commercial oil samples and six lab-hydrodistilled oils from three basil cultivars in mid-flowering cultivated in Australia, three from frozen fresh and three from dried plant material (ref. 58); [h] fifteen lab-hydrodistilled oils from three *O. basilicum* cultivars harvested monthly in a period 5 months in Morocco, partly in full bloom (ref. 44); [i] twelve lab-hydrodistilled oils from flowering basil plants collected in the wild and in gardens at several places in Benin; only eight components were investigated (ref. 36); [j] twenty-four steam-distilled oils from the aerial parts of *O. basilicum* harvested at three locations in Mali and prepared from both fresh and dried plant material (ref. 14); [k] eight lab-distilled oils from Turkey prepared from the aerial parts of basil grown under four different nitrogen levels (ref. 24); [l] sixteen lab-hydrodistilled oils from two cultivars from Turkey grown under 8 different fertilization regimes (ref. 23); [m] thirteen lab-hydrodistilled oils from the aerial parts in full bloom of 13 basil cultivars grown in the USA (ref. 21); [n] fourteen lab-hydrodistilled oils from the aerial parts of two Iranian landraces, from fresh material and biomass dried in six different manners (ref. 63); [o] four lab-hydrodistilled oils from four basil cultivars in full bloom grown in India (ref. 62); [p] four lab-hydrodistilled oils from the above-ground parts over ligneous shoot fragments of four cultivars of *O. basilicum* at the beginning of flowering, cultivated in Poland (ref. 45); [q] four lab-hydrodistilled oils from the above ground parts in full bloom of two cultivars harvested in two seasons in India (ref. 4); [r] four lab-hydrodistilled oils from the aerial parts of *O. basilicum* at the beginning of the flowering cultivated in Iran under different irrigation regimes (ref. 50); [s] four lab-hydrodistilled oils from the aerial parts in full bloom of *O. basilicum* harvested in Pakistan in 4 seasons (ref. 56); [t] three lab-distilled oils from one cultivar of *O. basilicum* aerial parts in the flowering phase and from the varieties *purpurascens* and *diffiforme* (which are considered synonymous with *O. basilicum* L. by the Plant List) from Croatia (13,37); [u] two lab-hydrodistilled oils from the aerial parts in the blooming stage of two basil cultivars grown in northern India (ref. 17); [v] two lab-hydrodistilled oils from the aerial parts of flowering wild basil in Iran (ref. 16); [w] two lab-hydrodistilled oils from the leaves and flowering tops of basils collected in the wild in Tanzania, both with very atypical compositions (ref. 57);

[x] two samples of lab-hydrodistilled oil from the flowering tops of basil growing wild in Kenya (ref. 9); [y] one lab-hydrodistilled oil from the aerial parts of flowering *O. basilicum* cultivated in Serbia and Montenegro (ref. 60); [y1] data from various studies cited in ref. 69; because of the abundance of literature on basil oils, only chemicals which have *not* been found in any other study are mentioned here (ref. 69); [y2] incorrect identification (ref. 69); [z] one lab-hydrodistilled oil from the flowering above ground parts of endemic purple green leaved basil cultivated in north-west Iran (ref. 31); [z1] one lab-hydrodistilled oil from *O. basilicum* var. *purpurascens* aerial parts in the flowering stage cultivated in Iran (ref. 12); [z2] four lab-hydrodistilled oils from the aerial flowering parts of basil harvested in the wild in Iran and dried before distillation in four different manners (ref. 33); data which are partly also published in ref. 31 (under [z]), are not presented here again; [z3] one laboratory steam-distilled oil from basil in full bloom cultivated in Israel (ref. 23); [z4] one laboratory-prepared oil from the aerial parts in full bloom of basil cultivated in Italy (ref. 8); [z5] one lab-hydrodistilled oil from a basil cultivated in Mongolia and in full bloom (ref. 20); [z6] one lab-hydrodistilled oil from the aerial parts at the flowering stage of basil collected in the wild in Turkey (ref. 48); [z7] one lab-hydrodistilled basil oil from the flowering aerial parts of plants grown near a university campus in Taiwan (ref. 6); [z8] one steam-distilled oil from the aerial parts in bloom from basil cultivated in Cuba (ref. 28); [z9] one extremely atypical basil oil sample obtained by distillation from the aerial parts in the flowering stage of *O. basilicum* cultivated in Iran (ref. 43); [z10] one lab-hydrodistilled oil from the leaves and flowering tops of basil cultivated in Serbia (ref. 55); [z11] one lab-hydrodistilled oil from the flowering aerial parts of basil cultivated in Romania (ref. 61); [z12] one lab-hydrodistilled basil flower oil from Turkey (ref. 10); [z13] one lab-hydrodistilled oil from the aerial parts in full bloom of a basil cultivar from Iran (ref. 29); [z14] one lab-hydrodistilled and one steam-distilled oil sample from the aerial parts (flowering?) of basil from Turkey (ref. 39); [z15] one lab-hydrodistilled oil from the over-ground parts of basil (flowering?) cultivated in Turkey (ref. 18); [z16] one lab-hydrodistilled oil from basil collected in the wild in Algeria (ref. 46); [z17] one lab-hydrodistilled oil from basil growing wild in north-east India with a camphoreous odor (ref. 15); [z18] one commercial basil oil sample produced in Egypt (ref. 59); [z19] one lab-hydrodistilled oil from the aerial parts of basil purchased at a local market in Turkey (ref. 51); [z20] one commercial oil of unknown origin (ref. 38); [z21] one lab-hydrodistilled oil from a whole (flowering?) basil plant from Cameroon (ref. 22); [z22] one lab-hydrodistilled oil from the aerial (flowering?) parts of basil growing in the wild in southern Italy (ref. 49); [z23] nine lab-hydrodistilled oils from the flowering aerial parts of 9 *O. basilicum* cultivars from Brazil (ref. 34); only 4 components were investigated; [z24] several lab-hydrodistilled oils from the flowering aerial parts of basil cultivated in Iran; mean concentrations given (ref. 47); [z25] one lab-hydrodistilled oil from the inflorescences of basil from India; only linalool and methyl cinnamate were investigated (ref. 42); [z26] five lab-hydrodistilled oils from the aerial parts in the flowering stage of basils collected in vegetable gardens at five locations in Togo (ref. 53); [z27] data from various studies cited in ref. 65; [z28] data cited in ref. 27; [z29] data taken from ref. 25; [z30] data cited in ref. 28; [z31] lab-hydrodistilled oils from the above ground parts of flowering basil of 17 cultivars grown in Poland (ref. 35); [z32] one lab steam-distilled oil from the semi-wilted flowering tops of basil produced in Nepal (ref. 66); [z33] one steam-distilled oil from Madagascar; the sesquiterpene fraction was investigated; chemicals are indicated with +[z33], as their concentration (in the sesquiterpene fraction) cannot be compared with the other data (ref. 67); [z34] one commercial oil sample purchased from a German manufacturer (ref. 68); [z35] detailed examination of a lab-hydrodistilled methyl chavicol-rich oil from basil stem and leaves from the Philippines by solvent extraction, distillation and column chromatography (ref. 54)

tr: trace (in columns C, D and G^f: <0.05; in column G^o: <0.1); + present in the oil investigated, but quantity not stated

Table 5.4.4 Major constituents of basil oils

Constituent	CAS	Percentage and range						
	A	B (64)	C (2)	D (11)	E (3)	F (30)	G	
Linalool	78-70-6	0.6-55.8	66.4	79.5	74.3	60.2	33.0	75.9^{f}; 77.5^{p}; 83.6^{z23}; 98.9^{x}
Methyl chavicol	140-67-0	0.2-87.0	87.8	22.8	88.2	76.3	12.3	89.9^{i}; 90.0^{o}; 94.3^{q}; 94.6^{t}
Methyl eugenol	93-15-2	0-24.7	38.8	0.2	14.9	34.2	26.0	40.5^{j}; 74.5^{e}; 78.0^{z15}; 91.1^{d}
(*E*)-Methyl cinnamate	1754-62-7		7.4		38.7		74.5	16.7^{z14}; 31.9^{z3}; 41.9^{z31}; 82.4^{m}
1,8-Cineole	470-82-6	0.03-13.7	12.1	8.1	17.5	14.5	14.6	14.8^{m}; 15.3^{h}; 16.5^{r}; 54.3^{w}
Geranial	141-27-5	0-0.6	0.7	0.2	36.9			1.6^{j}; 24.6^{n}; 25.7^{z31}; 39.4^{o}
Neral	106-26-3	0.08-0.5		0.1		27.6		10.0^{v}; 20.8^{z31}; 22.7^{n}; 29.4^{o}
Eugenol	97-53-0	0.03-15.3	20.1	2.4	5.9	21.1	4.1	14.2^{i}; 24.8^{j}; 27.6^{p}; 29.0^{d}
epi-α-Cadinol	5937-11-1	0-7.1		9.3	1.8		8.3	7.6^{c}; 12.4^{s}; 17.3^{n}; 27.5^{z4}
α-*trans*-Bergamotene	13474-59-4	0.01-19.8		3.1	5.9		3.2	7.5^{f}; 7.6^{e}; 14.9^{i}; 15.8^{z4}; 17.5^{v}
Geraniol	106-24-1		0.9	5.1	6.8	3.9		4.3^{p}; 5.2^{o}; 12.5^{v}; 13.4^{f}; 16.5^{l}
β-Caryophyllene	87-44-5	0.02-1.4	1.0	0.5	5.2	4.2	43.0	7.5^{v}; 8.0^{i}; 10.7^{z31}; 14.9^{n}
Caryophyllene oxide	1139-30-6	0-0.2	0.5	0.1	1.1	2.0	13.9	1.1^{b}; 2.5^{z2}; 4.0^{z9}; 8.0^{n}; 11.4^{w}
Nerol	106-25-2		0.4	0.1	9.7	1.8		0.9^{z16}; 2.7^{n}; 11.2^{o}; 12.6^{z24}

LEGEND: SEE UNDER TABLE 5.4.3

Many chemotypes of essential oil of basil have been proposed, usually based on the amount of the prevailing ingredients, mostly linalool, methyl chavicol, eugenol, methyl eugenol and methyl cinnamate (3,4,5,7,11,12,14,64). Some are based on one (dominant) ingredient only (e.g., linalool type, methyl eugenol type, methyl chavicol type), others on combinations (e.g., methyl cinnamate/linalool type, methyl eugenol/linalool chemotype, linalool/eugenol type). In some studies, other chemicals have been found to be the major ingredient, including (*E*)-anethole (32), bergamotene (5), *trans*-α-bergamotene (16), β-bisabolene (11), borneol (43), τ-cadinol (8), camphor (9,15), β-caryophyllene (30), 1,8-cineole (57), citral (3,11), elemene (44), geranial (11,35,62), linalyl acetate (48), menthone (31,33), and (*E*)-myroxide (57). The main chemotypes have been reviewed in refs. 11 and 14. The linalool present in basil oils is always β-linalool. The presence of α-linalool may indicate that the oil in question is either forged or is synthetic basil oil (2).

Because of the abundance of literature on basil oils, we have focused on oils that were prepared from the flowering tops (few studies) or from the aerial parts of basil in full bloom (most studies), as these likely are the qualities commonly used in the pharmaceutical, cosmetic, aromatherapy and perfumery industries. Studies specifically mentioning basil *leaves* only as source material for essential oils (of which there are dozens) are not discussed (with the exception of ref. 54, as many components not found in any other study were mentioned there). However, some authors have shown that the chemical profiles of oils obtained from the leaves and those from the inflorescences (of the same plants) are largely comparable (4,6,9) and obviously, the aerial parts consist for a large part of leaves. All cultivars have been included in the search as were the *Ocimum basilicum* varieties *diffiforme* and *purpurascens*, which are synonyms of *O. basilicum* L. according to the Plant List. From review articles on basil oils (27,28,65,69), only data of chemicals *not* mentioned in other sources, reviewed here, are cited.

CONTACT ALLERGY/ALLERGIC CONTACT DERMATITIS

General

Contact allergy to/allergic contact dermatitis from basil oil has been reported in two publications only, both from occupational exposure in aromatherapists. In neither can a false-positive reaction due to the excited skin syndrome be excluded. In one case report, linalool may have been an allergen in basil oil (71).

Case reports

An aromatherapist had chronic hand dermatitis and was patch test positive to 17 of 20 oils used at her work (tested 1% and 5% in petrolatum), including basil oil (70). Two other aromatherapists had contact dermatitis (occupational in one) with allergies to multiple essential oils used at their work, including basil oil. Both patients also reacted to geraniol, α-pinene, the fragrance mix and various other fragrance materials. In addition, one proved to be allergic to linalool and linalyl acetate, the other to caryophyllene; α-pinene, linalool, geraniol and caryophyllene were demonstrated by GC-MS in basil oil (71). Linalool may be an important component of basil oil and has been found in concentrations of up to 55.8% in commercial basil oils (Table 5.4.3, column A).

LITERATURE

1 Pushpangadan P, George V. Basil. In: Peter KV, Ed. Handbook of herbs and spices, 2nd Ed., Vol. 1. Oxford-Cambridge-Philadelphia-New Delhi: Woodhead Publishing Ltd, 2012: Chapter 4, 55-72

2 Radulovíc, Blagojevíc PD, Miltojevíc AB. α-Linalool – a marker compound of forged/synthetic sweet basil (*Ocimum basilicum* L.) essential oils. J Sci Food Agric 2013; 93:3292-3303

3 Telci I, Bayram E, Yılmaz G, Avci B. Variability in essential oil composition of Turkish basils (*Ocimum basilicum* L.). Biochem System Ecol 2006;34:489-497

4 Verma RS, Padalia RC, Chauhana A. Variation in the volatile terpenoids of two industrially important basil (*Ocimum basilicum* L.) cultivars during plant ontogeny in two different cropping seasons from India. J Sci Food Agric 2012;92:626-631

5 Zheljazkov VD, Callahan A, Cantrell CL. Yield and oil composition of 38 basil (*Ocimum basilicum L.*) accessions grown in Mississippi. J Agr Food Chem 2008;56:241-245

6 Sheen L-Y, Tsai Ou Y-H, Tsai S-J. Flavor characteristic compounds found in the essential oil of *Ocimum basilicum* L. with sensory evaluation and statistical analysis. J Agric Food Chem 1991;39:939-943

7 Marotti M, Piccaglia R, Giovanelli E. Differences in essential oil composition of basil (*Ocimum basilicum* L.) Italian cultivars related to morphological characteristics. J Agric Food Chem 1996;44:3926-3929

8 Occhipinti A, Capuzzo A, Bossi S, Milanesi C, Maffei ME. Comparative analysis of supercritical CO_2 extracts and essential oils from an *Ocimum basilicum* chemotype particularly rich in T-cadinol. J Essent Oil Res 2013;25:272-277

9 Dambolena JS, Zunino MP, López AG, Rubinstein HR, Zygadlo JA, Mwangi JW, et al. Essential oils composition of *Ocimum basilicum* L. and *Ocimum gratissimum* L. from Kenya and their inhibitory effects on growth and fumonisin production by *Fusarium verticillioides*. Innov Food Sci Emerg Technol 2010;11:410-414

10 Chalchat J-C, Özcan MM. Comparative essential oil composition of flowers, leaves and stems of basil (*Ocimum basilicum* L.) used as herb. Food Chem 2008;110:501-503

11 Verma RS, Padalia RC, Chauhana A, Thul ST. Exploring compositional diversity in the essential oils of 34 *Ocimum* taxa from Indian flora. Ind Crops Prod 2013;45:7-19

12 Dolatabad SS, Moghaddam M, Chalajour H. Essential oil composition of four *Ocimum* species and varieties growing in Iran. J Essent Oil Res 2014;26:315-321

13 Carović-Stanko K, Orlić S, Politeo O, Strikić F, Kolak I, Milos M, et al. Composition and antibacterial activities of essential oils of seven *Ocimum* taxa. Food Chem 2010;119:196-201. Data also presented in ref. 37

14 Chalchat J-C, Garry R-P, Sidibé L, Harama M. Aromatic plants of Mali (I): Chemical composition of essential oils of *Ocimum basilicum* L. J Essent Oil Res1999;11:375-380

15 Purkayastha J, Nath SC. Composition of the camphor-rich essential oil of *Ocimum basilicum* L. native to northeast India. J Essent Oil Res 2006;18:332-334

16 Yavari M, Mirdamadi S, Masoudi S, Tabatabaei-Anaraki M, Larijani K, Rustaiyan A. Composition and antibacterial activity of the essential oil of a green type and a purple type of *Ocimum basilicum* L. from Iran. J Essent Oil Res 2011;23:1-4

17 Padalia RC, Verma RS. Comparative volatile oil composition of four *Ocimum* species from northern India. Nat Product Res 2011;25:569-575

18 Özcan M, Chalchat J-C. Essential oil composition of *Ocimum basilicum* L. and *Ocimum minimum* L. in Turkey. Czech J Food Sci 2002;20:223-228

19 Nurzyńska-Wierdak R. Sweet basil essential oil composition: relationship between cultivar, foliar feeding with nitrogen and oil content. J Essent Oil Res 2012;24:217-227

20 Shatar S, Altantsetseg S. Essential oil composition of some plants cultivated in Mongolian climate. J Essent Oil Res 2000;12:745-750

21 Vieira RF, Simon JE. Chemical characterization of basil (*Ocimum* spp.) based on volatile oils. Flavour Fragr J 2006;21:214-221

22 Amvam Zollo PH, Biyiti L, Tchoumbougnang F, Menut C, Lamaty G, Bouchet Ph. Aromatic plants of tropical central Africa. Part XXXII. Chemical composition and antifungal activity of thirteen essential oils from aromatic plants of Cameroon. Flavour Fragr J 1998;13:107-114

23 Nurzyńska-Wierdak R, Borowski B, Dzida K, Zawiślak G, Kowalski R. Essential oil composition of sweet basil cultivars as affected by nitrogen and potassium fertilization. Turk J Agric Forest 2013;37:427-436

24 Daneshian A, Gurbuz B, Cosge B, Ipek A. Chemical components of essential oils from basil (*Ocimum basilicum* L.) grown at different nitrogen levels. Int J Nat Engin Sci 2009;3:9-13

25 Bahl JR, Garg SN, Bansal RP, Naqvi AA, Singh V, Kumar S. Yield and quality of shoot essential oil from the vegetative, flowering and fruiting stage crops of *Ocimum basilicum* cv. Kusumohak. J Med Arom Plan Sci 2000;22:743-746. Data cited in ref. 27

26 Kamada T, Casali VWD, Barbosa LCA, Fortes ICP, Fingal FL. Phenotype plasticity of the essential oil in basil accesses (*Ocimum basilicum* L). Rev Bras Plant Med 1999;1:12-22. Data cited in in ref. 27

27 Lawrence BM. Progress in essential oils. Basil oil. In: Lawrence BM. Essential oils 2001-2004. Carol Stream, USA: Allured Publishing Corporation, 2006:293-301 (reprinted from Perfumer and Flavorist 2004;29(6):80-90)

28 Lawrence BM. Progress in essential oils. Basil oil. In: Lawrence BM. Essential oils 2005-2007. Carol Stream, USA: Allured Publishing Corporation, 2008:11-16 (reprinted from Perfumer and Flavorist 2005;30(2):72-79)

29 Omidbaigi R, Mirzai M, Moghadam MS. Chemical investigation of a new cultivar of purple basil (*Ocimum basilicum* cv. Opal) from Iran. J Essent Oil Bear Plants 2007;10:209-214

30 Vina A, Murillo E. Essential oil composition from twelve varieties of basil (*Ocimum spp*) grown in Colombia. J Braz Chem Soc 2003;14:744-749

31 Hassanpouraghdam MB, Hassani A, Shalamzari MS. Menthone and estragole rich essential oil of cultivated *Ocimum basilicum* L. from Northwest Iran. Chemija 2010;21:59-62. Data also published in ref. 33

32 Koba K, Poutouli PW, Christine R, Jean-Pierre C, Komla S. Chemical composition and antimicrobial properties of different basil essential oils chemotypes from Togo. Bangladesh J Pharmacol 2009;4:1-8

33 Hassanpouraghdam MB, Hassani A, Vojodi L, Farsad-Akhtar N. Drying method affects essential oil content and composition of basil (*Ocimum basilicum* L.) J Essent Oil Bear Plants 2010;13:759-766. Data also partly published in ref. 31

34 Serafinia LA, Fernandes Pauletti G, Duarte Rota L, Atti dos Santos AC, Agostini F, Zattera F, Moyna P. Evaluation of the essential oils from nine basil (*Ocimum basilicum* L.) cultivars planted in southern Brazil. J Essent Oil Bear Plants 2009;12:471-475

35 Nurzyńska-Wierdak R. Morphological and chemical variability of *Ocimum basilicum* L. (Lamiaceae). Mod Phytomorphol 2013;3:115-118

36 Yayi E, Moudachirou M, Chalchat JC. Chemotyping of three *Ocimum* species from Benin: *O. basilicum*, *O. canum* and *O. gratissimum*. J Essent Oil Res 2001;13:13-17

37 Carović-Stanko K, Fruk G, Satovic Z, Ivić D, Politeo O, Sever Z, et al. Effects of *Ocimum* spp. essential oil on *Monilinia laxa in vitro*. J Essent Oil Res 2013;25:143-148. Data also presented in ref. 13

38 Tognolini M, Barocelli E, Ballabeni V, Bruni B, Bianchi A, Chiavarini M, Impicciatore M. Comparative screening of plant essential oils: Phenylpropanoid moiety as basic core for antiplatelet activity. Life Sciences 2006;78:1419-1432

39 Özek T, Beis SH, Demirçakmak B, Baser KHC. Composition of the essential oil of *Ocimum basilicum* L. cultivated in Turkey. J Essent Oil Res 1995;7:203-205

40 Pino JA, Roncal E, Rosado A, Goire I. The essential oil of *Ocimum basilicum* L. from Cuba. J Essent Oil Res 1994;6:89-90

41 Fleisher Z, Fleisher A. Volatiles of *Ocimum basilicum* traditionally grown in Israel. J Essent Oil Res 1992;4:97-99

42 Singh RS, Bordoloi DN. Changes in the linalool and methyl cinnamate amounts in a methyl cinnamate-rich clone of *Ocimum basilicum* at different growth stages. J Essent Oil Res 1991;3:475-476

43 Farhang V, Amini J, Ebadollahi A, Sadeghi GR. *Ocimum basilicum* L. essential oil cultivated in Iran: chemical composition and antifungal activity against three *Phytophthora* species. Arch Phytopathol Plant Protect 2014;47:1696-1703

44 Belkamel A, Bammi J, Janneot V, Belkamel A, Dehbi Y, Douira A. Évaluation de la biomasse et analyse des huiles essentielles de trois variétés de basilic (*Ocimum basilicum* L.) cultivées au Maroc. Acta Botanica Gallica: Botany Letters 2008;155:467-476

45 Nurzyñska-Wierdak R. Morphological variability and essential oil composition of four *Ocimum basilicum* L. cultivars. J Essent Oil Bear Plants 2014;17:112-119

46 Brada M, Hadj Khelifa L, Achour D, Wathelet JP, Lognay G. Essential oil composition of *Ocimum basilicum* L. and *Ocimum gratissimum* L. from Algeria. J Essent Oil Bear Plants 2011;14:810-814

47 Omidbaigi R, Mirzaei M, Moghadam MS. Difference of growth traits, essential oil content and compositions between diploid and induced tetraploid plants of basil (*Ocimum basilicum* L.). J Essent Oil Bear Plants 2010;13:579-587

48 Ozcan M, Chalchat J-C. Essential oil composition of a new chemotype of basil (*Ocimum basilicum* L.) cultivating in Turkey. J Essent Oil Bear Plants 2004;7:155-159

49 Senatore F, De Fusco R, Grassia A, Moro CO, Rigano ED, Napolitano F. Chemical composition and antibacterial activity of essential oils from five culinary herbs of the Lamiaceae family growing in Campania, Southern Italy. J Essent Oil Bear Plants 2003;6:166-173

50 Omidbaigi R, Hassani A, Sefidkon F. Essential oil content and composition of sweet basil (*Ocimum basilicum*) at different irrigation regimes. J Essent Oil Bear Plants 2003;6:104-108

51 Figueredo G, Ünver A, Chalchat JC, Arslan D, Öcan MM. A research on the composition of essential oil isolated from some aromatic plants by microwave and hydrodistillation. J Food Biochem 2012;36:334-343

52 Pirmoradi MR, Moghaddam M, Farhadi N. Chemotaxonomic analysis of the aroma compounds in essential oils of two different *Ocimum basilicum* L. varieties from Iran. Chem Biodivers 2013;10:1361-1371

53 Sanda K, Koba K, Nambo P, Gaset A. Chemical investigation of *Ocimum* species growing in Togo. Flavour Fragr J 1998;13:226-232

54 Hasegawa Y, Tajima K, Toi N, Sugimura Y. Characteristic components found in the essential oil of *Ocimum basilicum* L. Flavour Fragr J 1997;12:195-200

55 Filip S, Vidovic S, Adamovic D, Zekovic Z. Fractionation of non-polar compounds of basil (*Ocimum basilicum* L.) by supercritical fluid extraction (SFE). J Supercrit Fluids 2014;86:85-90

56 Hussain AI, Anwar F, Sherazi STH, Przybylski R. Chemical composition, antioxidant and antimicrobial activities of basil (*Ocimum basilicum*) essential oils depends on seasonal variations. Food Chem 2008;108:986-995

57 Runyoro D, Ngassapa O, Vagionas K, Aligiannis N, Graikou K, Chinou I. Chemical composition and antimicrobial activity of the essential oils of four *Ocimum* species growing in Tanzania. Food Chem 2010;119:311-316

58 Lachowicz KJ, Jones GP, Briggs DR, Bienvenu FE, Palmer MV, Ting SST, et al. Characteristics of essential oil from basil (*Ocimum basilicum* L.) grown in Australia. J Agric Food Chem 1996;44:877-881

59 Sacchetti G, Medici A, Maietti S, Radice M, Muzzoli M, Manfredini S, et al. Composition and functional properties of the essential oil of Amazonian basil, *Ocimum micranthum* Willd., Labiatae in comparison with commercial essential oils. J Agric Food Chem 2004;52:3486-3491

60 Bozin B, Mimica-Dukic N, Simin N, Anackov G. Characterization of the volatile composition of essential oils of some Lamiaceae spices and the antimicrobial and antioxidant activities of the entire oils. J Agric Food Chem 2006;54:1822-1828

61 Stefan M, Zamfirache MM, Padurariu C, Trută E, Gostin I. The composition and antibacterial activity of essential oils in three *Ocimum* species growing in Romania. Cent Eur J Biol 2013;8:600-608

62 Padalia RC, Verma RS, Chauhan A, Chanotiya CS. Changes in aroma profiles of 11 Indian *Ocimum* taxa during plant ontogeny. Acta Physiol Plant 2013;35:2567-2587

63 Pirbalouti AG, Mahdad E, Craker L. Effects of drying methods on qualitative and quantitative properties of essential oil of two basil landraces. Food Chem 2013;141:2440-2449

64 Liber Z, Carovic-Stanko K, Politeo O, Strikic F, Kolak I, Milos M, Satovic Z. Chemical characterization and genetic relationships among *Ocimum basilicum* L. cultivars. Chem Biodivers 2011;8:1978-1989

65 Lawrence BM. Progress in essential oils. Perfum Flavor 1995;20(July/August):29-41

66 Yonzon M, Lee DJ, Yokochi T, Kawano Y, Nakahara T. Antimicrobial activities of essential oils of Nepal. J Essent Oil Res 2005;17:107-111

67 Gaydou EM, Faure R, Bianchini J-P, Lamaty G, Rakotonirainy O, Randriamiharisoa R. Sesquiterpene composition of basil oil. Assignment of the ^{1}H and ^{13}C NMR spectra of β-elemene with two-dimensional NMR. J Agric Food Chem 1989;37:1032-1037

68 Baratta MT, Dorman HJD, Deans SG, Figueiredo AC, Barroso JAG, Ruberto G. Antimicrobial and antioxidant properties of some commercial essential oils. Flavour Fragr J 1998;13:235-244

69 Lawrence BM. Progress in essential oils. Perfum Flavor 1998;23(Nov/Dec):35-50

70 Selvaag E, Holm J, Thune P. Allergic contact dermatitis in an aromatherapist with multiple sensitizations to essential oils. Contact Dermatitis 1995;33:354-355

71 Dharmagunawardena B, Takwale A, Sanders KJ, Cannan S, Roger A, Ilchyshyn A. Gas chromatography: an investigative tool in multiple allergies to essential oils. Contact Dermatitis 2002;47:288-292

Chapter 5.5 BAY OIL

DEFINITION

Bay oil (essential oil of bay) is the essential oil obtained from the leaves of the bay rum tree (West Indian bay), *Pimenta racemosa* (Mill.) J.W. Moore.

INCI NOMENCLATURE

Description/definition: Pimenta acris leaf oil is the volatile oil distilled from the leaves of the bay, *Pimenta acris*, Myrtaceae

INCI name EU: Pimenta acris leaf oil

INCI name USA: Pimenta acris (bay) leaf oil

Other names: Bay leaf oil

CAS registry number(s): 8006-78-8; 85085-61-6; 91721-75-4

EINECS number(s): 294-376-5

Pimenta racemosa var. *racemosa* and *Pimenta acris* (Sw.) Kostel are synonyms for *Pimenta racemosa* (Mill.) J.W. Moore (GRIN taxonomy for plants, The Plant List, 2).

ISO (INTERNATIONAL ORGANIZATION FOR STANDARDIZATION) STANDARD

ISO number: 3045

ISO name: Essential oil of bay

Botanical origin: *Pimenta racemosa* (Mill.) J.W. Moore

Parts of plant used: Leaf

ISO values: ISO values (minimum and maximum concentrations) are shown in Table 5.5.1.

Bay oil should not be confused with *sweet* bay oil, which is obtained from the leaves of *Laurus nobilis* L. (see Laurel leaf oil, Chapter 5.45).

THE PLANT, THE OIL, AND THEIR USES

Pimenta racemosa (Mill.) J.W. Moore, commonly known as bay, bayrum tree or West Indian bay, is a shrub or small slender tree 7.5-15 meters tall with very aromatic leaves. It is native to the Caribbean (West Indies) and northern South America, and is cultivated widely in tropical countries including Indonesia, West Indies, Venezuela, Mexico, Puerto Rico, Guyana, Jamaica, Tanzania (Zanzibar and Pemba) and Cameroon (2). It is used for producing bay rum, which is not for drinking, but is a fragrance for external use (GRIN Taxonomy for Plants; http://plants.jstor.org/). In the Caribbean, bay leaves are used for cooking rice dishes, soups and stews and for making tea. Other applications include its uses as air freshener and insect repellent. Bay leaves are also used in Caribbean folk medicine, e.g., to lower blood pressure, or for the treatment of digestive problems or headache (http://Latinfood.about.com). The dried fruits of the *P. racemosa* tree are used around the world as spice.

Essential oils may be obtained from the leaves and the fruits. They are used in perfumes, aftershaves, lotions enhancing hair growth and strength or acting against hair loss, and for commercial food flavoring. In addition, the essential bay leaf oil is important in Caribbean folk medicine and used for the treatment of rheumatism, toothache and other ailments because of its apparent anti-inflammatory and analgesic properties (2,3). It is also employed in aromatherapy practices (22).

CHEMICAL COMPOSITION

Bay oil is a clear mobile liquid of brownish to dark brown color, which has a spicy odor, reminding of cloves. The yield of essential oil from the leaves of *Pimenta racemosa* (Mill.) J.W. Moore generally varies from 0.8 to 1.4% of fresh leaves and from 2.5 to 3.5% when obtained from dried leaves. The main producing countries of this oil are West India and some countries in South America including Venezuela and Guyana.

Literature data (up to October 29, 2014) on the chemical composition of bay oils and unpublished analytical data from one of us (E.S.) are shown in Table 5.5.2 in alphabetical order. In geranium oils from various origins, over 110 chemicals have been identified. About 51% of these were found in a single reviewed publication only.

The major compounds found in bay oils from different sources are shown in Table 5.5.3; they include (highest concentrations in any study given) eugenol (92.9%), geranial (53.2%), methyl eugenol (48.1%), methyl chavicol (32.8%), neral (32.6%), myrcene (30.9%), 1,8-cineole (20.4%), and chavicol (17.1%). Well-known ingredients of bay oils that were present in high concentrations in one study were β-pinene (22.9%), terpinen-4-ol (20.7%), α-terpineol (10.0%), *p*-cymene (8.0%) and geraniol (7.5%).

Commercial oils

The ten chemicals that had the highest maximum concentrations in 33 commercial bay essential oil samples (concentration ranges provided) are the following: eugenol (41.4-54.0%), myrcene (20.5-32.0%), chavicol (6.6-10.8%), limonene (2.4-3.2%), linalool (0.5-2.7%), terpinolene (0.1-2.1%), β-caryophyllene (0.4-1.9%), β-pinene (0.05-1.8%), dimyrcene (0.2-1.5%) and (*E*)-ocimene (0.7-1.3%) (Erich Schmidt, unpublished analytical data).

Chemotypes

There appear to be (at least) three chemotypes of bay oil. In Guadeloupe, three varieties of *Pimenta racemosa* (Mill.) J.W. Moore may be found (16). They are identical in their external morphology, but can easily be distinguished from the smell of their leaves. One of them, known as the common bay tree, is particularly abundant and is characterized by the smell of clove from its leaves and fruits. The other two varieties are rather rare and have smells of lemon and anise. The common clove type proved to contain eugenol (56%) and chavicol (17%) as main ingredients (the eugenol-chavicol chemotype). This is the commercial type essential oil of bay. The lemon type was dominated by geranial (40%) and neral (32%) (geranial-neral type), whereas the anise type of the bay tree had methyl eugenol (48%) and methyl chavicol (33%) as main ingredients (methyl eugenol-methyl chavicol type) (16). The anise and lemon type had previously also been demonstrated in bay oils from the Dominican Republic (15,17) and in even far older studies (cited in ref. 15). Early reports of high concentrations of citral (up to 65%) (cited in ref. 15) and α-humulene, β-caryophyllene and limonene (cited in refs. 9,10) have remained unsubstantiated. In one report from Cuba, terpinen-4-ol (21%) was the ingredient with the highest concentration (14, data also reported in refs. 7, 12 and 21). By far, most oils of which the analyses have been reported and which are discussed here had eugenol as main ingredient accompanied by high concentrations of chavicol, myrcene or both (Table 5.5.2).

Table 5.5.1 ISO values (%) for bay oil[a]

Compound	CAS	Minimum	Maximum
Eugenol	97-53-0	42	56
Myrcene	123-35-3	20	30
Chavicol	501-92-8	8.0	13.0
Limonene	138-86-3	1	4
Linalool	78-70-6	1	3
Methyl eugenol	93-15-2	0.1	2

[a] ISO Essential oil of bay ©ISO 2004; Geneva, Switzerland, www.iso.org

Table 5.5.2 Constituents identified in bay oils

Constituent	CAS	Percentage and range					
		A	B (3)	C (2)	D (9)	E (16)	F
Acetone	67-64-1						tr[f]
Acetyl chavicol	61499-22-7						0.3[j]
α-Amorphene	20085-19-2				0.4		
Anethole	104-46-1					0.2	0.1[h]
Aromadendrene	489-39-4				0.09		
allo-Aromadendrene	25246-27-9				0.3		
Bergamotene							0.2[d]
Borneol	507-70-0						0.8[c]
α-Cadinene	24406-05-1			0.08			0.5[c]
β-Cadinene	523-47-7				tr		
γ-Cadinene	39029-41-9	0.03-0.2		0.2	0.2		
δ-Cadinene	483-76-1	0.4-0.7	0-0.2	0.6	1.0	0.8	0.01[f]; 0.5[d]; 1.5[b]
α-Cadinol	481-34-5				0.3	0.2	0.02[f]
γ-Cadinol	50895-55-1				tr		
τ-Cadinol	5937-11-1		0-0.2				0.2[c]
Calamenene	483-77-2					0.2	
cis-Calamenene	72937-55-4				0.01		
Camphene	79-92-5				0.1		
Camphor	76-22-2				tr	1.5	
δ3-Carene	13466-78-9						0.2[c]
trans-2-Caren-2-ol							0.1[f]
Carvacrol	499-75-2						0.01[f]
Carveol	99-48-9						0.1[f]
β-Caryophyllene	87-44-5	0.4-1.9	0-0.3	0.5	7.2	0.6	0.02[f]; 0.2[j]; 0.4[a]; 0.7[b]; 4.0[d]; 4.9[i]
Caryophyllene oxide	1139-30-6	0.02-1.0				0.1	0.03[f]
β-Chamigrene	18431-82-8				0.2		
Chavicol	501-92-8	6.6-10.8	7.1-9.3	9.3	15.5	17.1	7.7[b]; 8.9[e]; 10.1[h]; 10.3[j]; 10.4[d]; 10.5[a]
Chrysanthenone	473-06-3					1.6	
1,8-Cineole	470-82-6	0.1-0.6	2.1-3.2	0.7	1.4	1.2	1.1[a]; 1.3[c]; 3.2[l]; 4.7[j]; 9.7[e]; 20.4[h]
Cinnamaldehyde	104-55-2				0.1		
Citronellal	106-23-0						0.04[f]
Citronellyl acetate	150-84-5						0.08[f]
α-Copaene	3856-25-5	0.2-0.6		0.3	0.4	0.4	0.3[a]; 1.3[d]
α-Cubebene	17699-14-8			tr			
Cyclocitral	52844-21-0						0.2[f]
α-Cyclocitral	432-24-6					0.2	
p-Cymene	99-87-6	0.4-0.7	0.4-0.9	0.5	1.0	0.5	0.2[f]; 0.4[l]; 0.5[c]; 0.8[a]; 1.7[e]; 8.0[h]
p-Cymenene	1195-32-0				0.3		0.2[h]
p-Cymen-8-ol	1197-01-9				tr	0.1	0.6[c]
Decanal	112-31-2	0.02-0.1					
(*Z*)-4-Decenal	21662-09-9						<0.06[f]
2,3-Dehydro-1,8-cineole	92760-25-3					0.1	0.3[f]
Dimyrcene	532-87-6	0.2-1.5					
β-Elemene	33880-83-0				0.2		
Eugenol	97-53-0	41.4-54.0	45.2-52.7	45.6	68.9	56.1	46.3[a]; 52.7[c]; 54.5[j]; 60[d]; 64[i]; 92.9[b]
Eugenyl acetate	93-28-7				0.5		0.2[c]
α-Farnesene	502-61-4	0.1-0.8			0.6		

Table 5.5.2 Constituents identified in bay oils (*continued*)

Constituent	CAS	Percentage and range					
		A	B (3)	C (2)	D (9)	E (16)	F
(*E*,*E*)-α-Farnesene	502-61-4		0-0.3	0.5		0.2	0.3[l]
Geranial	141-27-5	0.06-0.3		0.06	0.2	40.3	0.2[h]; 41.3[f]; 53.2[g]
Geranic acid	459-80-3					1.0	0.07[f]
Geraniol	106-24-1	0.05-0.1		0.08	0.1	3.5	0.2[a]; 2.8[g]; 7.5[f]
Geranyl acetate	105-87-3						0.4[f]
Geranyl formate	105-86-2						0.01[f]
Germacrene D	23986-74-5					0.3	0.05[f]; 0.5[b]
Globulol	489-41-8				0.4		
α-Gurjunene	489-40-7			0.01	0.1		
Hexanol	111-27-3						0.05[f]
(*E*)-2-Hexenal	6728-26-3						0.02[f]
(Z)-3-Hexenol	928-96-1						0.2[f]
γ-Homogeraniol							0.3[f]
α-Humulene	6753-98-6	0.1-0.3	0-0.1	0.4	1.3	0.2	0.01[f]; 0.3[b]
Ibuprofen	15687-27-1						0.2[j,k]
Isoeugenol	97-54-1			0.7			0.3[c]
Limonene	138-86-3	2.4-3.2	3.0-4.0	2.9	3.9	5.3	1.9[g]; 2[i]; 3.1[a,c]; 3.4[l]; 3.8[b]; 6.0[e]
Linalool	78-70-6	0.5-2.7	0.1-2.1	2.3	3.6	6.0	1.6[i]; 1.9[c]; 2.2[d]; 2.6[a]; 3.0[g]; 3.2[e]; 3.4[f]
cis-Linalool oxide	11063-77-7	0.01-0.03		0.09			
cis-Linalool oxide, furanoid	5989-33-3						0.06[f]
trans-Linalool oxide	11063-78-8					0.1	
trans-Linalool oxide, furanoid	34995-77-2						0.07[f]
Menthadienol							2.1[f]
6-Methoxyeugenol	6627-88-9						0.3[h]
2-Methyl-3-buten-2-ol	115-18-4						tr[f]
Methyl chavicol	140-67-0	0.01-0.4		0.3	0.05	32.8	0.1[a]; 0.8[h]; 1.3[d]; 31.6[g]
Methyl cinnamate	103-26-4						0.1[h]
Methyl eugenol	93-15-2	0.04-1.3		1.0	11.9	48.1	0.2[e]; 0.3[h]; 0.5[a]; 5.4[d]; 43.1[g]
6-Methyl-5-hepten-2-one	110-93-0					0.3	0.2[g]; 0.9[a]; 1.1[f]
α-Muurolene	10208-80-7				0.5		
γ-Muurolene	30021-74-0						0.02[f]
γ-Muurolol	138068-73-2				tr		
Myrcene	123-35-3	20.5-32.0	21.9-30.9	25.0	16.2	12.8	9.6[b]; 14.6[i]; 21.3[e]; 25.9[a]; 26.6[c]; 30.9[l]
Neral	106-26-3	0.02-0.2		0.09		31.7	0.2[h]; 31.7[f]; 32.6[g]
Neric acid	37349-29-4					0.2	0.1[f]
Nerol	106-25-2			0.4			
(*E*)-Nerolidol	40716-66-3			0.5			
Neryl acetate	141-12-8						0.09[f]
(*E*)-2-Nonenal	18829-56-6						<0.06[f]
Ocimene	13877-91-3						2.3[e]
(*E*)-Ocimene	27400-72-2	0.7-1.3					
(*E*)-β-Ocimene	3779-61-1		0-0.3	0.9	1.4	0.4	0.2[c,f]; 0.3[g,l]
(*Z*)-Ocimene	27400-71-1	0.05-0.1					0.4[j]
(*Z*)-β-Ocimene	3338-55-4			0.1	0.1	0.1	0.04[f]; 0.2[b]; 0.3[c]
n-Octanol (1-)	111-87-5	0.01-0.2		0.2			0.3[h]
3-Octanol	589-98-0	0.3-0.7		0.7	0.8	3.0	0.1[g]; 0.3[e]; 0.4[b]
3-Octanone	106-68-3	0.1-1.1		0.8	1.1		0.4[d]; 0.7[b]; 0.8[e]
1-Octen-3-ol	3391-86-4	0.7-1.1	1.3-2.4	0.9	1.7		0.2[f]; 1.3[g]; 1.5[h]; 1.6[c,e]; 1.9[l]
α-Phellandrene	99-83-2	0.3-0.6		0.4	0.5	0.3	0.1[a,f,g]; 0.7[b,c]; 0.8[j]; 1.6[h]
β-Phellandrene	555-10-2	0.04-1.0		0.4			0.1[g]; 1.1[e]
α-Pinene	80-56-8	0.3-0.4	0.3-0.6	0.5	0.5	0.5	0.1[b,g]; 0.2[f]; 0.4[a]; 0.5[j,l]; 1.9[e]; 2.0[h]
β-Pinene	127-91-3	0.05-1.8	0-0.1	0.07	0.09		0.3[h]; 0.4[e]; 22.9[j]
Sabinene	3387-41-5				tr		0.3[h]; 1.4[j]
α-Selinene	473-13-2				0.6		
β-Selinene	17066-67-0				0.3		
Spathulenol	6750-60-3				0.1		
α-Terpinene	99-86-5	0.09-0.2	0.1-0.6	0.2	0.2		0.02[f]; 0.1[b,h]; 0.3[j]; 0.6[l]
γ-Terpinene	99-85-4	0.07-0.2	0-0.2	0.2	0.2	0.1	0.04[f]; 0.1[b]; 0.3[j]; 4.6[h]
Terpinen-4-ol	562-74-3	0.2-0.6	0.7-0.9	0.5	0.9	1.2	0.5[j]; 0.6[d]; 0.7[a]; 0.9[e]; 1.9[l]; 20.7[h]
α-Terpineol	98-55-5	0.06-0.7	0.7-0.9	0.07	0.5	0.5	0.3[a,c]; 0.4[j]; 0.9[l]; 2.3[e]; 10.0[h]

Table 5.5.2 Constituents identified in bay oils (*continued*)

Constituent	CAS	Percentage and range					
		A	**B (3)**	**C (2)**	**D (9)**	**E (16)**	**F**
Terpinolene	586-62-9	0.1-2.1	0-0.3	0.4	0.2	0.1	0.03[f]; 0.1[g]; 3.1[h]
α-Thujene	2867-05-2	0.01-0.3		0.08	tr		0.02[f]; 0.1[j]; 0.2[c]; 1.1[h]; 1.9[e]
α-Thujone	546-80-5					0.1	0.1[g]
Thymol	89-83-8						0.3[j]
Torreyol	19435-97-3		0-0.3				
Verbenol	473-67-6					1.0	1.1[f]
Viridiflorene (ledene)	21747-46-6						0.01[f]

A thirty-three essential oil samples from West India analyzed between 2003 and 2013; lowest and highest concentrations given (E. Schmidt, unpublished data)
B six lab-prepared oil samples from leaves of *P. racemosa* growing wild in Benin, collected in two places in the years 2003, 2004 and 2005; lowest and highest concentrations given (ref. 3)
C one commercial oil from Jamaican bay rum tree prepared in Germany (ref. 2)
D two commercial bay leaf oils from unknown origin; highest concentrations given (ref. 9)
E one lab-hydrodistilled oil from leaves of 'clove-type' *P. racemosa* from Guadeloupe (eugenol-chavicol chemotype), one from the lemon variety (geranial-neral chemotype) and one from leaves of the anise variety (methyleugenol-methylchavicol type) (ref. 16)
F data from other studies (indicated with superscript letters); highest concentrations found in any study reviewed here given; when two or more oils were investigated, only the highest concentrations are mentioned, unless indicated otherwise

[a] one commercial oil sample purchased in South Korea (ref. 1); [b] two lab-prepared oil samples from leaves harvested in spring and autumn in North India (ref. 4); [c] one lab-hydrodistilled oil collected from leaves of a bay rum tree growing wild in Benin (ref. 10); [d] one commercial oil of unknown origin (ref. 11); [e] one bay oil sample, origin unknown (ref. 6); [f] one hydrodistilled oil from leaves harvested in Guadeloupe of the geranial-neral chemotype (ref. 8); [g] one steam-distilled oil from leaves from the lemon variety and one from the anise variety of *P. racemosa* harvested in the Dominican Republic (ref. 15); [h] one lab-hydrodistilled oil from leaves of *P. racemosa* growing wild in western Cuba (ref. 14; data apparently also presented in refs. 7, 12 and 21); [i] one lab-hydrodistilled leaf oil from plant material purchased from a Czech company (ref. 18); [j] one lab-hydrodistilled *P. racemosa* leaf oil from plant material harvested in the wild in Benin (ref. 19); [k] misidentification; [l] one lab-hydrodistilled oil from the leaves of *P. racemosa* grown at a farm in Benin (ref. 20);

tr: trace (in columns D and F[f]: <0.01);

CONTACT ALLERGY/ALLERGIC CONTACT DERMATITIS

General

Contact allergy to bay oil has been reported in one publication, but no cases of allergic contact dermatitis from the oil have been identified. In a group of fragrance sensitive patients reacting to bay oil, eugenol may have been an important allergen.

Testing in groups of patients

In a group of 21 patients with dermatitis caused by fragrances and tested with a series of essential oils, nine (43%) reacted to oil of bay 1.5% in petrolatum; relevance data were not provided (23). Bay oil consists of 40-55% of eugenol, and as eugenol is an important cause of fragrance sensitivity, the high percentage of positive reactions to bay oil (43%) in this fragrance-sensitive population may be ascribed to eugenol. Indeed, of the seven patients reacting

Table 5.5.3 Major constituents of bay oils

Constituent	CAS	Percentage and range					
		A	**B (3)**	**C (2)**	**D (9)**	**E (16)**	**F**
Eugenol	97-53-0	41.4-54.0	45.2-52.7	45.6	68.9	56.1	46.3[a]; 52.7[c]; 54.5[j]; 60[d]; 64[i]; 92.9[b]
Geranial	141-27-5	0.06-0.3		0.06	0.2	40.3	0.2[h]; 41.3[f]; 53.2[g]
Methyl eugenol	93-15-2	0.04-1.3		1.0	11.9	48.1	0.2[e]; 0.3[h]; 0.5[a]; 5.4[d]; 43.1[g]
Methyl chavicol	140-67-0	0.01-0.4		0.3	0.05	32.8	0.1[a]; 0.8[h]; 1.3[d]; 31.6[g]
Neral	106-26-3	0.02-0.2		0.09		31.7	0.2[h]; 31.7[f]; 32.6[g]
Myrcene	123-35-3	20.5-32.0	21.9-30.9	25.0	16.2	12.8	9.6[b]; 14.6[i]; 21.3[e]; 25.9[a]; 26.6[c]; 30.9[l]
1,8-Cineole	470-82-6	0.1-0.6	2.1-3.2	0.7	1.4	1.2	1.1[a]; 1.3[c]; 3.2[l]; 4.7[j]; 9.7[e]; 20.4[h]
Chavicol	501-92-8	6.6-10.8	7.1-9.3	9.3	15.5	17.1	7.7[b]; 8.9[e]; 10.1[h]; 10.3[j]; 10.4[d]; 10.5[a]
β-Caryophyllene	87-44-5	0.4-1.9	0-0.3	0.5	7.2	0.6	0.02[f]; 0.2[j]; 0.4[a]; 0.7[b]; 4.0[d]; 4.9[i]
Limonene	138-86-3	2.4-3.2	3.0-4.0	2.9	3.9	5.3	1.9[g]; 2[i]; 3.1[a,c]; 3.4[l]; 3.8[b]; 6.0[e]
Linalool	78-70-6	0.5-2.7	0.1-2.1	2.3	3.6	6.0	1.6[i]; 1.9[c]; 2.2[d]; 2.6[a]; 3.0[g]; 3.2[e]; 3.4[f]

LEGEND: SEE UNDER TABLE 5.5.2

to bay oil and tested with eugenol, five (71%) co-reacted to eugenol (23).

LITERATURE

1 Kim J, Lee Y-S, Lee S-G, Shin S-C, Park I-K. Fumigant antifungal activity of plant essential oils and components from West Indian bay (*Pimenta racemosa*) and thyme (*Thymus vulgaris*) oils against two phytopathogenic fungi. Flavour Fragr J 2008;23:272-277

2 Jirovetz L, Buchbauer G, Stoilova I, Krastanov A, Stoyanova A, Schmidt E. Spice plants: Chemical composition and antioxidant properties of *Pimenta* Lindl. essential oils, part 2: *Pimenta racemosa* (Mill.) J.W. Moore leaf oil from Jamaica. Ernährung/Nutrition 2007;31: 293-300

3 Alitonou GA, Noudogbessi J-P, Sessou P, Tonouhewa A, Avlessi F, Menut C, et al. Chemical composition and biological activities of essential oils of *Pimenta racemosa* (Mill.) J.W. Moore from Benin. Int J Biosc 2012;2:1-12

4 Pragadheesh VS, Yadav A, Singh SC, Gupta N, Chanotiya CS. Leaf essential oil of cultivated *Pimenta racemosa* (Mill.) J.W. Moore from North India: Distribution of phenylpropanoids and chiral terpenoids. Med Aromat Plants 2013;2:118. Available at http://dx.doi.org/10.4172/2167-0412.1000118

5 Lawrence BM. Progress in essential oils. Perfum Flavor 2000;25 (July/Aug):55-70

6 Buttery RG, Black DR, Guadangi DG, Ling LC, Connolly G, Teranishi R. California bay oil. 1. Constituents, odor properties. J Agric Food Chem 1974;22:773-777 (cited in ref. 5)

7 Bello A, Urquiola A, Garcia JJ, Rosado A, Pino JA. Essential oil from leaves of *Pimenta racemosa* (Mill.) J.W. Moore (Myrtaceae) from Western Cuba. Ing Cienc Quim 1998;18:21-23 (cited in ref. 5)

8 Chapron N, Parfait A, Bourgeois P. Industrial importance of essential oils of 'Bois d'Inde' - *Pimenta racemosa* var. *racemosa* (M. Miller) J.W. Moore. Rivista Ital. EPPOS (Numero Speciale) 1998;467-474 (cited in ref. 5)

9 Tucker AM, Maciarello MJ, Adams RP, Landrum LR, Zanoni TA. Volatile leaf oils of Caribbean Myrtaceae. I. Three varieties of *Pimenta racemosa* (Milller) J. Moore of the Dominican Republic and the commercial bay oil. J Essent Oil Res 1991;3:323-329

10 Ayedoun AM, Adeoti BS, Setondji J, Menut C, Lamaty G, Bessière J-M. Aromatic plants from tropical West Africa. IV. Chemical composition of leaf oil of *Pimenta racemosa* (Miller) J.W. Moore var. *racemosa* from Benin. J Essent Oil Res 1996;8:207-209

11 Delespaul Q, de Billerbeck VG, Roques CG, Michel G, Marquier-Vinuales C, Bessière J-M. The antifungal activity of essential oils as determined by different screening methods. J Essent Oil Res 2000;12:256-266

12 Bello A, Pino J, Marbot R, Urquiola A, Aguero J. Components volátiles des plantas de la famila Myrtaceae de la región occidental de Cuba. Revista CENIC Cienc Quim 2001;32:143-147 (cited in ref. 13)

13 Lawrence BM. Progress in essential oils. Bay oil. Perfum Flav 2007;32 (July):46-52

14 Bello A, Rodriguez ML, Castiñeira N, Urquiola A, Rosado A, Pino JA. Chemical compositon of the leaf oil of *Pimenta racemosa* (Mill.) J. Moore from Western Cuba. J Essent Oil Res 1995;7:423-424

15 McHale D, Laurie WA, Woof MA. Composition of West Indian bay oils. Food Chem 1977;2:19-25

16 Abaul J, Bourgeois P, Bessiere JM. Chemical composition of the essential oils of chemotypes of *Pimenta racemosa* var. *racemosa* (P. Miller) J. W. Moore (Bois d'Inde) of Guadeloupe (F.W.I.). Flavour Fragr J 1995;10:319–321

17 Ames GR, Barrow M, Borton C, Casey, T, Matthews WS, Nabney J. Bay oil distillation in Dominica. Tropical Science 1971;13:13

18 Zabka M, Pavela R, Prokinova E. Antifungal activity and chemical composition of twenty essential oils against significant indoor and outdoor toxigenic and aeroallergenic fungi. Chemosphere 2014;112:443-448

19 Tchobo FP, Alitonou GA, Soumanou MM, Barea B, Bayrasy C, Laguerre M, et al. Chemical composition and ability of essential oils from six aromatic plants to counteract lipid oxidation in emulsions. J Am Oil Chem Soc 2014;91:471-479

20 Keke M, Yehouenou B, de Souza C, Sohounhloue D. Evaluation of hygienic and nutritional quality of peulh cheese treated by *Sorghum vulgaris* (L) and *Pimenta racemosa* (Miller) extracts. Scientific Study and Research 2009;10:29-46

21 Leyva M, Tacoronte JE, Marquetti Mdel C. Chemical composition and lethal effect of essential oil from *Pimenta racemosa* (Myrtales: Myrtaceae) on *Blatella germanica* (Dictyoptera: Blattellidae) (article in Spanish). Rev Cubana Med Trop 2007;59:154-158

22 Rhind JP. Essential oils. A handbook for aromatherapy practice, 2nd Edition. London: Singing Dragon, 2012

23 Meynadier JM, Meynadier J, Peyron JL, Peyron L. Formes cliniques des manifestations cutanées d'allergie aux parfums. Ann Dermatol Venereol 1986;113:31-39.

Chapter 5.6 BERGAMOT OIL

DEFINITION

Bergamot oil (essential oil of bergamot) is the essential oil obtained from the pericarp (peel) of the bergamot orange, *Citrus bergamia* (Risso et Poit.)

INCI NOMENCLATURE

Bergamot fruit oil

Description/definition: Citrus aurantium bergamia fruit oil is the psoralen-free volatile oil obtained from the fruit of *Citrus aurantium* L. var. *bergamia*, Rutaceae

INCI name EU: Citrus aurantium bergamia fruit oil

INCI name USA: Citrus aurantium bergamia (bergamot) fruit oil

Other names: bergamot oil bergaptene free; bergamot oil rectified

CAS registry number(s): 8007-75-8; 68648-33-9

EINECS number(s): 616-915-9; 614-687-5 (not EINECS numbers, but numbers in the EC format)

Bergamot peel oil

Description/definition: Citrus aurantium bergamia peel oil is the volatile oil obtained from the peel of *Citrus aurantium bergamia*, Rutaceae

INCI name EU: Citrus aurantium bergamia peel oil

INCI name USA: Citrus aurantium bergamia (bergamot) peel oil

CAS registry number(s): 89957-91-5

EINECS number(s): 289-612-9

BERGAMOT PEEL OIL EXPRESSED

Description/definition: Citrus bergamia peel oil expressed is the essential oil expressed from the epicarps of the bergamot, *Citrus bergamia risso*, Rutaceae

INCI name EU: Citrus aurantium bergamia peel oil expressed (perfuming name, not an INCI name proper)

INCI name USA: not in the Personal Care Products Council Ingredient Database

Other names: Bergamot orange oil

CAS registry number(s): 89957-91-5; 85049-52-1

EINECS number(s): 289-612-9

ISO (INTERNATIONAL ORGANIZATION FOR STANDARDIZATION) STANDARD

ISO number: 3520

ISO name: Essential oil of bergamot, Italian type

Botanical origin: *Citrus bergamia* (Risso et Poit.) (synonym: *Citrus aurantium* L. subsp. *bergamia* (Wight et Arnott) Engler)

Parts of plant used: Pericarp (peel)

ISO values: ISO values (minimum and maximum concentrations) are shown in Table 5.6.1.

By ISO definition, all citrus essential oils except lime oil are produced by expression; oils obtained from citrus fruits by distillation may not be called essential oils according to ISO criteria (except lime oil). In industry, however, sometimes residues from expression of the citrus peels undergo steam distillation, to obtain the remaining oil; these volatile oils may then be added to the expressed oil. As some of the compounds undergo changes forced by high temperature during distillation, this addition (which is an adulteration) changes the composition of the essential oil. Because of this, and also because it cannot be excluded that oils entirely produced by hydrodistillation reach the market, both the ingredients found in 'genuine' bergamot essential oils obtained by expression and those that may be present in hydrodistilled oils are presented here.

THE PLANT, THE OIL, AND THEIR USES

Bergamot is the common name of the fruit and plant of *Citrus bergamia* Risso et Poiteau. It is a small tree that blossoms during the winter, producing a fragrant pale yellow, spherical fruit 7.5-10 cm in diameter, which has a bitter taste but a pleasant odor (31). Its origin is uncertain, but probably lies in the Mediterranean region. *Citrus bergamia* is commercially grown mainly in the southern Italian region of Calabria in the area of Reggio Calabria, limited to a narrow strip of the coast, along the Ionian and the Thyrrenian seas, of about 150 km. Here, more than 90% of the world production is realized (23,25). Bergamot is also cultivated and industrially processed in Ivory Coast, Brazil and China. Small cultivations are registered in Turkey, Argentina, Uruguay, Cameroon, and in some countries in North Africa (27,31). The fruit is almost exclusively grown for the production of essential peel oil, not for juice consumption. Recently, however, bergamot has been reconsidered, along with other *Citrus* fruits, as an ingredient of traditional Mediterranean cooking (27).

Bergamot essential oils are obtained by cold extraction, generally using 'pelatrice'-type machines. From the residues of the cold extraction, oils of lower quality can be recovered with distillation techniques and chemical modification such as 'torchiati', 'ricicli', 'pulizia dischi', 'distilled' and 'bergapten-free' bergamot oils (see below, under Phototoxicity of bergamot oil) (27, 35).

Among the *Citrus* peel oils, because of its unique fragrance and freshness, bergamot essential oil is the most valuable and is therefore mainly employed in the perfumery (e.g., in the original Eau de Cologne) and cosmetic industries, where it may be used in skin care creams and lotions for its cooling and refreshing nature (15,25,38). The oil also serves for the flavoring of sweets, tobacco, liqueur (curaçao), tea, e.g., Earl Grey tea (37), baked goods, desserts, chewing gum and soft drinks (23,27). Because of its antiseptic and antibacterial properties, bergamot oil is inserted in the pharmacopoeia of several countries and is used in the pharmaceutical industry (23,25) and in sanitary preparations (15). Both in folk medicine and in aromatherapy (where it is a popular oil [15,32]), bergamot oil is perceived as analgesic,