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# Relationship between Bioactivity and Chemical Composition of Commercial Essential Oils†

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ABSTRACT: In order to establish the value of the use of biological activities as accessory criteria (in conjunction with gas chromatography, but in the absence of enantiomeric analysis) for establishing the authenticity of essential oils, the biological activities of 105 commercial essential oils were investigated against 25 species of bacteria, 20 strains of *Listeria monocytogenes*, and three filamentous fungi; their antioxidant action was also determined and all the results were related to the actual chemical composition of the oils as determined by gas chromatography. The results showed some relationship between the major components and some bioactivities. There was a negative correlation between 1,8-cineole content and antifungal activity. There was, however, great variability between the biological action of different samples of individual oils and groups of oils under the same general name, e.g. lavender, eucalyptus or chamomile, which was reflected in differences in chemical composition, The results suggest that, although the biological activities are not all related to the main components, any significant blending, rectification and adulteration of commercial oils can be monitored by their biological activities. The use of essential oils named simply as 'chamomile' or 'eucalyptus', or any commercial oil which has been adulterated, cannot be justifiably used in treating medical conditions unless it can be shown that the action is non-specific and independent of the chemical composition. 

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KEY WORDS: essential oils; antibacterial activity; antifungal activity; antioxidant activity; anti-*Listeria monocytogenes* activity; chemical composition and bioactivity; adulteration

## Introduction

The authenticity of commercial essential oils has been investigated recently using sophisticated enantiomeric analyses with various cyclodextrin phases.[1] However, the main usage of essential oils is biological, i.e. for fragrance, flavour and therapeutics (mainly aromatherapy). The best way to test adulteration may therefore be through the use of biological systems.

Many essential oils have strong to medium antimicrobial activities,[2–10] some have pharmacological properties[11,12] and some have been shown to have an effect on the brain[13] and behaviour.[14] Many essential oils are used in aromatherapy to cure numerous clinical conditions:[15] the essential oils used are, however, frequently interchangeable, depending on other pervading characteristics in the patient, e.g. emotional state. The oils themselves may be chosen for their colour, 'Yin and Yang' characteristics, etc. From the scientific point of view, such interchanges are extremely difficult to justify. The differences between different generic forms of 'chamomile', 'lavender', 'eucalyptus' or 'geranium' oils should first be looked at.

Roman and German chamomile oils are almost invariably treated as one by aromatherapists and many scientists (as noted in the literature), although their chemical composition, as well as the odour, is widely different and therefore their biological activity may be different; recently, Moroccan chamomile oil has been used in preference (due to its lower cost), and this oil is again of an entirely different composition and therefore likely to have different biological activity. This hypothesis was therefore tested against several biological parameters *in vitro*. The study also set out to investigate whether differences in commercial samples of an individual oil could be shown by differences in biological activities and whether there was any correlation between any chemical component of essential oils and any of the biological activities.

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## Experimental

### Essential Oils and Analysis

Essential oils were obtained from a number of commercial sources and analysed by GC and GC–MS.[12] GC analysis was carried out using a Shimadzu GC 8A and an OV-101 column (50 m × 0.32 mm), programmed at 4°C/min, with injection temperature 230°C. GC–MS analysis was carried out using a JEOL AX 505W, and a BP-1 column (25 m × 0.22 mm).

### Antibacterial Studies

Antibacterial studies were conducted *in vitro* against 25 different Gram-positive and Gram-negative bacteria[6] and 20 strains of *Listeria monocytogenes* obtained from different sources.[9] All assays were carried out in triplicate using seeded Iso-sensitest agar (Oxoid Ltd), with 4 mm holes punched out into which 10 µl of essential oil were pipetted. The plates were incubated in the dark at 25°C for 48 h and the zone of inhibition was determined using vernier calipers.

### Antifungal Studies

Antifungal studies were conducted against three filamentous fungi: *Aspergillus niger*, *A. ochraceus* and *Fusarium culmorum*. The essential oils were introduced at 1 µl/ml and 10 µl/ml in 10 ml of YES broth;[16] after 10 days the weights of the fungi were recorded after drying. Values approaching 100 mean very high activity.

### Antioxidant Studies

Antioxidant activity was measured using 10 ml $\beta$-carotene (2 mg/ml in acetone), 2.0 ml of linoleic acid (2 mg/ml in ethanol) in 100 ml of 2.0 g% bacto-agar. 100 µl Essential oil were added and the plates incubated at 45°C until the background colour was bleached. The intensity of colour remaining was also recorded as part of the antioxidant activity.[16]

## Results and Discussion

The essential oil activity against 25 different bacteria showed similarities with the results of Deans and Ritchie[6] and Maruzella and Sicurella[3] in that the oils of clove, dill, cinnamon, bay, angelica and pimento were excellent antimicrobial agents (Table 1) as was also cumin oil.[4] Camphor and the oils of bergamot, cassia, frankincense, ho-wood, niaouli, palmarosa, rosewood and tea tree were also found to be effective against a wide range of bacteria. Poor activity was shown by the oils of aniseed, basil, carrot, cedarwoods, fennel, lemon, myrrh and patchouli.

The activity against *Listeria monocytogenes* strains partly reflected this trend. The action against the fungi used as test organisms was often directly related to the antibacterial action, with a few exceptions, e.g. angelica, orange and rosemary.

Thyme oil has been reported to be effective against both bacteria[6] and some fungi.[2] However, in the present studies, where two or more samples of the 'same' oil were assessed, different results were often found, e.g. only two of three thyme oils were active (Table 2). The two red thyme oils were similar in composition, but different from the sweet thyme (which contained 30% geraniol and 50% geranyl acetate, in contrast to the Spanish thyme which contained 45–48% thymol and 19–21% *p*-cymene); there was, however, a difference in the anti-*Listeria* activity between the two Spanish thymes. There was no great difference in the antibacterial activity of the marjoram oils but their anti-*Listeria*, antifungal and antioxidant actions were variable: there was no relationship between the bioactivity and the chemical composition (Table 3).

The biological activities of the six chamomile oil samples were variable but in general low (Tables 4 and 5). The best antibacterial effect was shown by one of the Moroccan oils, which had almost twice the concentration of santolina alcohol as the other. The other chamomile samples showed quite a low bioactivity. There was a bigger difference in activity between the pairs of Roman, Moroccan and German chamomiles than between the different species themselves.

The strong antibacterial activity of the verbena, lemongrass and *Litsea* oils could be associated with a high citral content (Table 6). Their antifungal activity was high except against *F. culmorum*, and the antioxidant action was detected only for the oils of verbena and lemongrass.

Lavender oil has been used as a healing agent for burns for half a century,[17] and it has received acclaim as an antiseptic.[15] A large variety of 'lavenders' are on the market, differing in both name and chemical composition. The biological action of the different commercial 'lavenders' studied was in fact very variable (Table 7); this, however, could not be correlated with the major oil components: for example, the two Bulgarian lavender oils showed of high antibacterial activity but inconsistent antifungal activity, which was reflected by the substantial variation in the composition of the two oils. The carbon dioxide-extracted oil had 80% linalyl acetate compared with 9.5% in the other, whilst the former had 2.3% linalol and the latter 52%. Spike lavender was equally as active against the 25 bacteria as the first lavender sample, but their linalol and linalyl

**Table 1.** Bioactivity of commercial essential oils

| Essential oil | Antibacterial activity[a] Number affected | | Antifungal activity[b] *Aspergillus niger* | *Aspergillus ochraceus* | *Fusarium culmorum* |
|---|---|---|---|---|---|
| Angelica root | 23 | 20 | 0 | 16 | −18 |
| Aniseed | 6 | 0 | 83 | 82 | 69 |
| Basil | 15 | 20 | 94 | 76 | 71 |
| Bay | 25 | 20 | 95 | 80 | 69 |
| Bergamot | 23 | 20 | 13 | 31 | 34 |
| Bergamot FCF | 22 | 20 | 70 | 30 | 89 |
| Cajeput | 21 | 19 | −12 | 30 | −1 |
| Camphor | 25 | 20 | 95 | 96 | 0 |
| Cardamom | 14 | 15 | 89 | 19 | 40 |
| Carrot | 3 | 0 | 7 | 0 | 24 |
| Cassia | 23 | 20 | 87 | 89 | 54 |
| Cedarwood, Atlas | 2 | 0 | 0 | 0 | 0 |
| Cedarwood, Chinese | 3 | 0 | 6 | 7 | 4 |
| Cedarwood, Texas | 3 | 0 | 6 | 7 | 5 |
| Cedarwood, Virginia | 4 | 0 | 8 | 17 | 14 |
| Celery | 17–25 | 19 | 13–25 | 35–48 | 31–36 |
| Chamomile (6) | 2–14 | 0–11 | −1–63 | 5–56 | −18–75 |
| Clary sage | 11–18 | 9–15 | 72–92 | 91–96 | 67–69 |
| Clove bud | 23 | 20 | 95 | 94 | 73 |
| Clove leaf | 24 | 20 | 93 | 94 | 73 |
| Cinnamon leaf | 24 | 20 | 95 | 94 | 73 |
| Cumin | 22 | 18 | 91 | 92 | 67 |
| Dill | 20 | 11 | 95 | 90 | 88 |
| Eucalyptus (3) | 10–21 | 6–20 | 0–87 | 24–61 | −18–78 |
| Fennel | 6 | 0 | 95 | 78 | 66 |
| Frankincense | 24 | 18 | 7 | 65 | 28 |
| Geranium (16) | 8–18 | 3–16 | 0–94 | 12–95 | 40–86 |
| Ho-wood | 23 | 15 | 73 | 93 | 81 |
| Lavender (7) | 13–23 | 0–18 | 57–93 | 29–90 | 31–89 |
| Lemongrass | 18 | 20 | 90 | 83 | 63 |
| Lemon | 8 | 3 | 4 | 22 | 0 |
| *Litsea* | 16–18 | 18–19 | 87–94 | 80–90 | 40–64 |
| Marjoram (4) | 23–25 | 15–20 | 16–84 | 8–79 | 26–48 |
| Melissa | 22 | 9 | 89 | 73 | 60 |
| Myrrh | 6 | 6 | 0 | 21 | 4 |
| Myrtle | 22 | 17 | 10 | 3 | 15 |
| Niaouli | 24 | 19 | 85 | 79 | 46 |
| Neroli | 20–22 | 11–19 | 66–86 | 43–90 | 63–71 |
| Nutmeg | 18–19 | 0–12 | 46–88 | 41–86 | 20–72 |
| Orange | 19 | 10 | 0 | 34 | 84 |
| Palmarosa (2) | 21–23 | 17–18 | 73–92 | 55–79 | 55–78 |
| Patchouli | 6 | 15 | 6 | 29 | 27 |
| Peppermint (20) | 15–22 | 13–20 | 80–98 | 70–93 | 47–85 |
| Petitgrain | 21 | 16 | 61 | 69 | 78 |
| Pimento berry | 25 | 20 | 96 | 82 | 65 |
| Pine needle | 19 | 18 | 11 | 18 | 16 |
| *Ravensara aromatica* | 20 | 16 | 27 | 35 | −12 |
| Rosewood | 24 | 12 | 72 | 63 | 71 |
| Rosemary | 21 | 16 | 12 | 14 | 0 |
| Sage, Dalmatian | 16 | 6 | 0 | 53 | 33 |
| Tea tree | 24 | 20 | 85 | 91 | 76 |
| Thyme (3) | 14–25 | 6–20 | 91–96 | 61–92 | 75–86 |
| Verbena | 18 | 20 | 86 | 85 | 61 |

Numbers in parentheses indicate number of samples in group; the range of activity is then given.
[a] Antibacterial activity tested against 25 different bacteria (left column) and against 20 strains of *Listeria monocytogenes* (right column).
[b] Antifungal properties calculated from formula:

$$\frac{C - T}{C} \times 100$$

where C = weight of mycelium in control flask; T = weight of mycelium in test flask.

acetate content were widely different. The anti-*Listeria* activity was also variable in that spike lavender was only effective against 12/20 strains, while the first lavender was only effective against one strain.[10] This variability in bioactivity between oils from different commercial outlets was further exemplified by geranium oil, a sample of which was found by Deans and Ritchie[6] to be one of the top 10 antibacterial oils, but when 16 different commercial samples were studied, a wide range of activity was found between the samples

**Table 2.** Bioactivity of thyme and marjoram essential oils

| Essential oil | Antibacterial activity:[a] No. affected | Antioxidant value[b] | Antifungal activity[c] *Aspergillus niger* | *Aspergillus ochraceus* | *Fusarium culmorum* |
|---|---|---|---|---|---|
| Thyme sweet | 14 | 15.0 + | 95 | 88 | 83 |
| Thyme red Spanish | 25 | 13.8 +++ | 91 | 92 | 86 |
| Thyme red | 25 | 21.6 ++ | 96 | 61 | 75 |
| Marjoram sweet | 23 | 9.2 + | 55 | 66 | 27 |
| Marjoram Spanish | 23 | 10.4 ++ | 41 | 67 | 39 |
| Marjoram Spanish | 23 | 0 | 16 | 8 | 26 |
| Marjoram French | 25 | 8.1 + | 84 | 79 | 48 |

[a] Antibacterial activity tested against 25 different bacteria.
[b] Antioxidant value, diameter of zone of colour retention; + very modest, ++ modest, +++ marked colour retention.
[c] Antifungal activity calculated as in Table 1.

**Table 3.** Main components of the commercial thyme and marjoram essential oils

| Essential oil | Main components (%) |
|---|---|
| Thyme sweet | Geraniol (30.4), geranyl acetate (50.1) |
| Thyme red Spanish | *p*-Cymene (21.4), thymol (47.5) |
| Thyme red | *p*-Cymene (18.5), thymol (45.0) 1,8-Cineole (15.3) |
| Marjoram sweet | 1,8-Cineole (57.9), terpinolene (18.3) |
| Marjoram Spanish | 1,8-Cineole (61.3), terpinolene (19.7) |
| Marjoram Spanish | 1,8-Cineole (49.9), terpinolene (10.6) |
| Marjoram French | Terpinen-4-ol (29.2), terpinolene (13.5) $\gamma$-Terpinene (16.2) |

affecting 8–18 different bacteria (Table 1) and 3–16 *Listeria* strains,[9] and none of the biological activities could be correlated with the major components, as in the case of lavender oils above.

The apparent correlation between antifungal activity and contents of linalol and linalyl acetate in the essential oils, shown in Table 7, was tested graphically but showed a wide scatter and no real correlation and therefore statistical analysis was abandoned. Samples of neroli oil, with distinctly different linalol contents, showed similar antibacterial activity but different antifungal activity (which was related to the linalol content); the two samples of bergamot oil, with similar linalyl acetate contents, showed similar antibacterial activity but not antifungal or antioxidant action. The two clary sage samples, however, with a similar linalol content, showed variable biological activity.

The four cedarwood oils tested showed similar, although almost completely ineffective, biological activity despite different stated origins and presumed different compositions (Table 1), which in fact were quite similar (not shown). The high cedrene and thujopsene content, together with a high cedrol content, is therefore not conducive to high biological action. According to the present results, the good 'antiseptic' claim for cedarwood[15] is grossly exaggerated.

Substantial biological activity was shown by some of the Myrtaceae oils and this suggested that 1,8-cineole may be responsible for this activity. Essential oils with high 1,8-cineole levels were therefore assessed for their biological activity (Table 8). There was no direct correlation shown, except for an inverse correlation between the 1,8-cineole content and the antifungal activity ($r = -0.73$, $-0.57$ and $-0.76$ for *A. niger*, *A. ochraceus* and *F. culmorum* respectively). Again, this apparent negative correlation was not notable when plotted graphically. There is no clear explanation for a negative correlation, as one of the major attributes of tea tree oil is its antifungal property and it now appears that the 1,8-cineole content can enhance fungal growth. It is of note that anti-*Listeria* activity (as well as pharmacological action[10]) was extremely high for *E. citriodora* (with a high citronellal content) compared to *E. globulus* (with 91% cineole); the latter is the normal commercial 'eucalyptus' oil used for aromatherapy due to its supposed great antimicrobial activity! The antimicrobial activity of tea tree oil has also been

**Table 4.** Bioactivity of commercial chamomile oils

| Essential oil | Antibacterial activity:[a] No. affected | | Antifungal activity[b] *Aspergillus niger* | *Aspergillus ochraceus* | *Fusarium culmorum* | Antioxidant value[c] |
|---|---|---|---|---|---|---|
| Roman 1 | 2 | 0 | −1 | 5 | −18 | 0 |
| Roman 2 | 4 | 0 | 39 | 26 | 62 | 0 |
| German 1 | 2 | 0 | 62 | 56 | 25 | 10.5 + |
| German 2 | 5 | 1 | 63 | 40 | 75 | 13.6 ++ |
| Moroccan 1 | 14 | 11 | 31 | 34 | −10 | 13.0 + |
| Moroccan 2 | 5 | 1 | 43 | 53 | 23 | 0 |

[a] Antibacterial activity tested against 25 different bacteria (left column) and against 20 strains of *Listeria monocytogenes* (right column)
[b] Antifungal activity calculated as in Table 1.
[c] Antioxidant value (as in Table 2).

**Table 5.** Major components of the commercial chamomile oils

| Essential oil | Major components (%) |
|---|---|
| Roman 1 | isobutyl butyrate (6.2), isobutyl angelate (34.6), isoamyl angelate (21.1) |
| Roman 2 | isobutyl butyrate (5.1), isobutyl angelate (15.1), isoamyl angelate (20.3) |
| German 1 | *trans*-β-Farnesene (17.9), α-bisabolol oxide B (5.9), α-bisabolol (6.4), chamazulene (2.8), α-bisabolol oxide A (46.0) |
| German 2 | *trans*-β-Farnesene (28.3), α-bisabolol oxide B (3.9), α-bisabolol (8.5), chamazulene (1.3), α-bisabolol oxide A (45.1) |
| Moroccan 1 | α-Pinene (8.1), limonene (5.6), santolina alcohol (45.5), *trans*-pinocarveol (7.9), bornyl acetate (2.0), β-caryophyllene (3.3), bisabolene (2.5), germacrene (5.5) |
| Moroccan 2 | α-Pinene (13.4), limonene (7.6), santolina alcohol (24.2), *trans*-pinocarveol (4.4), bornyl acetate (2.1), β-caryophyllene (1.6), bisabolene (1.1), germacrene (1.2) |

linked to components other than 1,8-cineole, which on its own showed poor activity.[18]

Strong bioactivity was observed when the major component was eugenol, as in the oils of pimento (82–85%), clove bud and leaf (83%), bay (62%) and cinnamon leaf (82%). There was less pronounced bioactivity where the major components were geraniol, citronellol and linalol. Methylchavicol (basil oil, 92%) and carotol (carrot oil, 78%) were not conducive to strong antimicrobial activity. Cinnamon bark and cassia oils with cinnamaldehyde levels of 79% were very active.

Essential oils with high monoterpene hydrocarbon levels were very active against bacteria although not against fungi, with the exception of dill (Table 9), where the high carvone content may have influenced the results; the relationship was apparent when the terpenes included pinenes, camphene, α-terpinene, γ-terpinene, myrcene or limonene (Table 10). Essential oils with high monoterpene hydrocarbon content were also

**Table 6.** Relationship between high citral content of commercial essential oils and bioactivity

| Essential oil | Citral (%) | Antibacterial activity:[a] No. affected | | Antifungal activity[b] | | | Antioxidant value[c] |
|---|---|---|---|---|---|---|---|
| | | | | *Aspergillus niger* | *Aspergillus ochraceus* | *Fusarium culmorum* | |
| Verbena | 35.5 | 18 | 20 | 86 | 85 | 61 | 17.7 |
| Lemongrass | 78.6 | 18 | 20 | 90 | 83 | 63 | 8.9 |
| *Litsea* 1 | 44.9 | 16 | 18 | 87 | 80 | 40 | 0 |
| *Litsea* 2 | 80.6 | 18 | 19 | 94 | 90 | 64 | 0 |

[a] Antibacterial activity tested against 25 different bacteria (left column) and 20 strains of *Listeria monocytogenes* (right column).
[b] Antifungal activity calculated as in Table 1.
[c] Antioxidant value (as in Table 2).

**Table 7.** Correlation between high linalol or linalyl acetate content of commercial essential oils and bioactivity

| Essential oil | Linalol (%) | Linalyl acetate (%) | Antibacterial activity:[a] No. affected | Antifungal activity[b] | | |
|---|---|---|---|---|---|---|
| | | | | *Aspergillus niger* | *Aspergillus ochraceus* | *Fusarium culmorum* |
| Lavender 1 | 29.7 | 42.8 | 19 | 82 | 90 | 79 |
| Lavender Bul | 51.9 | 9.5 | 23 | 84 | 29 | 8 |
| Spike lavender | 43.1 | 4.0 | 19 | 93 | 58 | 31 |
| Lavender Fr 1 | 26.1 | 47.9 | 16 | 93 | 58 | 31 |
| Lavender Fr 2 | 29.1 | 43.2 | 13 | 57 | 44 | 77 |
| Lavandin | 28.7 | 39.4 | 17 | 93 | 86 | 69 |
| Lavender Bul[c] | 2.3 | 79.8 | 22 | 74 | 84 | 89 |
| Ho-wood | 94.3 | 0 | 23 | 73 | 93 | 81 |
| Rosewood | 93.9 | 0 | 24 | 72 | 63 | 71 |
| Neroli 1 | 93.9 | trace | 22 | 86 | 90 | 71 |
| Neroli 2 | 23.8 | 68.5 | 20 | 66 | 43 | 63 |
| Clary sage 1 | 24.2 | 62.0 | 18 | 72 | 96 | 69 |
| Clary sage 2 | 22.9 | 54.2 | 11 | 92 | 91 | 67 |
| Bergamot FCF | 21.9 | 37.6 | 22 | 70 | 30 | 89 |
| Bergamot | 11.0 | 38.5 | 23 | 13 | 31 | 34 |
| Petitgrain | 18.9 | 54.7 | 21 | 61 | 69 | 78 |
| Myrtle | 9.8 | 2.9 | 22 | 10 | 3 | 15 |

Fr = French. Bul = Bulgarian.
[a] Antibacterial activity tested against 25 different bacteria.
[b] Antifungal activity calculated as in Table 1.
[c] Extracted with supercritical carbon dioxide.
$r = 0.73$ for linalol vs *Aspergillus niger*.

**Table 8.** Correlation between 1,8-cineole content of commercial essential oils and bioactivity

| Essential oil | 1,8-cineole (%) | Antibacterial activity:[a] No. affected | | Antifungal activity[b] | | | Antioxidant value[c] |
|---|---|---|---|---|---|---|---|
| | | | | *Aspergillus niger* | *Aspergillus ochraceus* | *Fusarium culmorum* | |
| *E. globulus*[d] | 90.8 | 14 | 6 | 2 | 24 | −18 | 0 |
| *E. radiata*[e] | 84.0 | 21 | 20 | 0 | 35 | 36 | 0 |
| Cajeput[f] | 69.3 | 21 | 19 | −12 | 30 | 34 | 13.4 + |
| *Ravensara*[g] | 65.6 | 20 | 16 | 27 | 35 | −12 | 0 |
| Niaouli[h] | 57.6 | 24 | 19 | 85 | 79 | 46 | 7.6 + |
| Rosemary | 49.9 | 21 | 16 | 12 | 14 | 0 | 0 |
| Camphor | 47.9 | 25 | 20 | 95 | 96 | 0 | 0 |
| Tea tree[i] | 7.1 | 24 | 20 | 85 | 91 | 76 | 0 |
| *E. citriodora*[j] | 0.6 | 10 | 20 | 87 | 61 | 78 | 0 |

[a] Antibacterial activity tested against 25 different bacteria (left column) and 20 strains of *Listeria monocytogenes* (right column).
[b] Antifungal activity calculated as in Table 1.
[c] Antioxidant value as in Table 2.
[d] *Eucalyptus globulus* (Myrtaceae); [e] *Eucalyptus radiata* (Myrtaceae); [f] *Melaleuca cajeputi* (Myrtaceae); [g] *Ravensara aromatica* (Lauraceae); [h] *Melaleuca quinquenervia* (Myrtaceae); [i] *Melaleuca alternifolia* (Myrtaceae); [j] *Eucalyptus citriodora* (Myrtaceae).
$r = -0.73$, 0.57 and 0.76 for *A. niger*, *A. ochraceus* and *F. culmorum*, respectively, against 1,8-cineole content.

**Table 9.** Relationship between high terpene hydrocarbon content of commercial essential oils and bioactivity.

| Essential oil | Antibacterial activity[a] | | Antifungal activity[b] | Antioxidant value[c] |
|---|---|---|---|---|
| Angelica | 23 | 20 | Poor | 0 |
| Bergamot | 22–23 | 20 | Poor–moderate | 0–14 |
| Celery | 17–25 | 19 | Poor | 0 |
| Dill | 20 | 11 | Good | 0 |
| Frankincense | 24 | 18 | Poor | 9.9 |
| Myrtle | 22 | 17 | Poor | 10.0 |
| Nutmeg | 18–19 | 0–12 | Poor–moderate | 13–23 |
| Pine needle | 19 | 18 | Poor | 0 |
| Rosemary | 21 | 16 | Poor | 0 |
| Cedarwoods | 2–4 | 0 | Poor | 0 |
| Myrrh | 6 | 6 | Poor | 0 |
| Patchouli | 6 | 15 | Poor | 0 |

[a] Antibacterial activity tested against 25 different bacteria (left column) and 20 strains of *Listeria monocytogenes* (right column).
[b] Antifungal activity calculated as in Table 1.
[c] AO = antioxidant value as in Table 2.
Antifungal activity expressed as: poor = 0–30% inhibition; poor to moderate = 30–50% inhibition; moderate = 50–70% inhibition.

**Table 10.** Major components of the essential oils with high terpene hydrocarbon contents

| Essential oil | Components (%) |
|---|---|
| Angelica | α-Pinene 26%, limonene 22%, α-terpinene 11% |
| Bergamot | Limonene 31–38%, α-pinene 2–4% |
| Celery | Limonene 68%, β-selinene 12% |
| Dill | Limonene 37% |
| Frankincense | α-Pinene 42%, *p*-cymene 22%, limonene 7%; α-thujene 7% |
| Myrtle | α-Pinene 17%, limonene 31% |
| Nutmeg | α-Pinene 15–20%, β-pinene 11–23%, sabinene 8–12%, limonene 5–6% |
| Pine needle | α-Pinene 15%, camphene 22%, 3-carene 10%, limonene 7% |
| Rosemary | α-Pinene 11%, myrcene 7%, camphene 4% |
| Cedarwoods | Thujopsene 10–26%, α-cedrene 21–33%, β-cedrene 3–7% |
| Myrrh | Curzerene 16%, lindestrene 3% |
| Patchouli | α-Guaiene 16.5%, bulnesene 21%, β-caryophyllene 3.4% |

spasmogenic when tested against guinea-pig ileum *in vitro*.[20] There is at present no explanation for this relationship. Oils of myrrh, patchouli and cedarwoods, containing high proportions of sesquiterpene hydrocarbons (Table 10), were almost inactive (Table 9).

In conclusion, the essential oils which have been shown to be linked with consistently high biological activities against micro-organisms *in vitro*, even fungi, are those containing cinnamaldehyde, eugenol and citral, as their main components. This is in agreement with the results of Moleyar and Narasimham,[5] who

only studied antifungal action. Other components in essential oils showing variable though frequently high effectiveness were linalol, linalyl acetate, 1,8-cineole, thymol and many monoterpene hydrocarbons. There was, however, no consistent relationship between *all* the biological activities and most individual essential oils, and often inverse relationships occurred between antibacterial action and antifungal action (Table 9). The antioxidant activity proved to be variable (even for the thyme oils, which are usually very consistent) and it may be that the method used was not ideal. This variability could also suggest that there was addition of synthetic antioxidants in some cases (giving positive results) and not in others.

There is a direct relationship between essential oils with a spasmogenic action on guinea-pig ileum smooth muscle and a high pinene content, which is also related to a high antibacterial activity.[8] Many of these essential oils also have a stimulating action on man *in vivo*, as shown by special brain wave pattern changes or CNV (contingent negative variation).[13,14]

The fact that variable biological activities were produced by chamomile or eucalyptus oils from different biological origins may not be in support of the claims made in many aromatherapy books that many essential oils from different species, but from the same family, are interchangeable. However, it may be possible that the effects found *in vitro* cannot be extrapolated to those *in vivo*. The aromatherapeutic action of essential oils may occur mainly through the action of the odour on nasal mucosal sensory cells, which relay the message via the limbic system and finally a specific cellular action ensues. It is not known whether the odour profile requires specificity of composition, i.e. whether it is important to have all the components or the correct enantiomers present, etc.

The study also showed that there was often a variation in the actual chemical composition between similarly labelled essential oils, which was also apparent in bioactivity measurements.

Adulteration of commercial essential oils often involves the admixing of different fractions from several essential oils derived from completely different species: this will usually result in a different proportion of enantiomers to that of the 'named' essential oil. Studies on the bioactivity of limonene enantiomers have shown considerable differences in the same bioactivities as assessed in the present study.[19] The present results therefore support the view that adulteration has occurred in many samples.

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