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## Chemical composition and antimicrobial activity of a newly identified chemotype of Achillea wilhelmsii K.Koch from Kashan, Iran

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Achillea wilhelmsii K.Koch (Asteraceae) is traditionally used in Kashan (Iran) to control diabetes, headaches, kidney stones and heartburn. Due to its beneficial properties, the aerial parts of the plant were collected from the area of Maragheh (Kashan, Isfahan, Iran), in June 2022, during its full flowering, and the essential oil was obtained by hydrodistillation (Clevenger). The yield, composition and antimicrobial activity of the extractive solution were measured. Qualitative evaluation was performed by means of gas chromatography-mass spectroscopy method, and antimicrobial activity was determined against 12 strains of microorganisms by measuring inhibition halo, minimum inhibitory concentration, and minimum bactericidal concentration (MBC). The yield of essential oil was ~ 0.1071% (w/w) and it mainly contained oxygenated monoterpenes (47.87%), being for the first time fragranol (33.22%), fragranyl acetate (16.18%) and oleic acid (6.33%) the most abundant. The highest inhibitory halo was found against Candida albicans and Gram-positive Staphylococcus aureus (~10 mm). The essential oil was also effective against gram-negative bacteria such as Acinetobacter baumannii and Shigella dysenteriae, as the inhibition halo was ~9 mm and similar to that of rifampin, used as a reference. Therefore, it seems that this essential oil from and endemic species has a unique chemotype with potential antimicrobial activity, which may be a possible option for fragranol isolation and the production of natural antibiotics effective against various microorganisms.

Keywords Achillea, Essential oil quantity, Fragranol, Antibacterial/yeast activity, Ethnobotany

Medicinal plants have long been used for various purposes such as manufacturing medicines, cosmetics, foods, and nutritional supplements. Moreover, indigenous populations often rely on herbal formulations for treating different disorders due to their effectiveness, affordability, accessibility, and limited side effects<sup>1–3</sup>. These products contain multiple valuable natural molecules with different biological and therapeutic activities, representing a significant and unexploited natural resources<sup>4</sup>. Research into the effects of medicinal plants and the discovery of new drugs holds great promise in countering the increasing resistance of pathogens to antibiotics, which complicates the treatment of microbial diseases<sup>5</sup>.

Essential oils, often rich in natural molecules with antibacterial properties, have been used since ancient times to prevent bacterial growth and spoilage. Despite their potential, their effectiveness has not been fully exploited yet<sup>6</sup>. Previous studies have highlighted the antimicrobial potential of essential oils from aromatic plants against various pathogens, including foodborne pathogens, bacteria (both Gram-negative and Gram-positive), viruses, and yeasts responsible for human diseases<sup>7,8</sup>. The antibacterial properties of essential oils may vary depending on factors such as the plant family, climatic and soil conditions, harvesting time, and extraction method<sup>9</sup>. Plants of the Asteraceae family, known for their aromatic properties, often produce essential oils rich in antimicrobial molecules. These oils have been extensively used in both folk and modern medicine<sup>10</sup>. The genus *Achillea*, within the Asteraceae family, comprises numerous herbaceous species distributed across temperate regions of Asia and

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Europe<sup>11,12</sup>. Several species of *Achillea*, including *Achillea wilhelmsii* K.Koch (*A. wilhelmsii*), are renowned for their medicinal properties and pleasant aroma<sup>13,14</sup>. The word "yarrow" is derived from the Greek word "Achill", signifying "hero", reflecting the historical use of the genus in treating diseases during wars<sup>15</sup>. In Iran, Achillea species, locally known as "Bomadaran", have a significant presence in traditional medicine, attributed to their various pharmacological effects, including reducing blood pressure and cholesterol, regulating menstrual cycles, and alleviating numerous ailments<sup>16–19</sup>. Additionally, different studies have confirmed the moderate to strong antibacterial properties of plants of this genus<sup>20</sup>.

Among Achillea species, *Achillea wilhelmsii* K.Koch (*A. wilhelmsii*) is a chamaephyte native to the South and East Mediterranean, Central Asia, and Pakistan. It is characterized by stems with compact white felt hairs, lobed yellow flowers, and tubular flowers<sup>18,21</sup>. *Achillea wilhelmsii* is used for various medicinal purposes across different regions, including inducing abortion, alleviating stomach pain and fever, and treating jaundice in children<sup>22</sup>. Ethnobotanical studies reveal its various uses in different parts of Iran, ranging from treating heart aches and respiratory infections to regulating menstrual cycles and counteracting diarrhea<sup>23–25</sup>. Pharmacological investigations have reported its anti-ulcer, anti-proliferative, anti-anxiety, antioxidant, anti-inflammatory, and antimicrobial properties<sup>26–31</sup>.

Previous studies have reported varying levels of inhibitory activity of *A. wilhelmsii* essential oil against bacterial strains such as *Escherichia coli*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and others<sup>32–34</sup>. The essential oil mainly contains camphor and 1,8-cineol<sup>19,33,35,36</sup>.

To the best of our knowledge, the essential oil of *A. wilhelmsii* from the Kashan region has not been previously analyzed and tested. Considering the potential pharmacological effects of this species, the identification of its chemotype is crucial. Therefore, this study aimed at evaluating for the first time the qualitative and quantitative chemical composition and antimicrobial activity of the essential oil of *A. wilhelmsii* grown in the natural habitat of Maragheh region (Kashan, Isfahan province, Iran).

#### Materials and methods

#### Collection and preparation of plant materials

The Kashan region, located in Isfahan, Iran, particularly the Maragheh area (coordinates N 33° 41′ 42″ and E 51° 26′ 78″), situated at an altitude of 2000–2200 m above sea level, was chosen for sample collection. Permission to collect plant material was obtained from the Agricultural Jahad Office. In June 2022, during full flowering, three plots of plants were randomly selected in this area. Epigean parts were randomly collected from 150 individuals in each plot, then transferred to the laboratory and dried at room temperature (20 °C and 40% relative humidity). Additionally, an herbarium sample was collected and stored at the Faculty of Natural Resources and Earth Sciences, University of Kashan, Iran. The plant was identified by Gianluigi Bacchetta and recorded with code number 1413.

#### Extraction and separation of essential oil

All plant experiments were carried out in accordance with guidelines. Extraction was performed using hydrodistillation method, wherein 90 g of ground sample were placed in a 2000 mL flask with approximately 1400 mL of distilled water, and connected to the Clevenger apparatus (Merck, Germany). Essential oil extraction was carried out for 3 h. The collected essential oil underwent sodium sulfate dehydration, and its weight was accurately measured using a precision balance to calculate the extraction yield<sup>37</sup>. The essential oil was then stored in glass bottles at 4 °C in the dark until further use. This extraction process was repeated three times.

#### Qualitative and quantitative analysis of essential oil

The qualitative and quantitative analysis of the essential oil was performed using a GC–MS device (model 6890) with an ionization energy of 70 eV and coupled with a mass spectrometer (model 5973 N, Agilent, America). A HP-5MS capillary column with 5% methylphenylsiloxane stationary phase (Length 30 m, Internal Diameter 0.25 mm, Layer Static Thickness 0.25  $\mu$ m) was used. A temperature gradient, starting from 60 °C and then increasing (at a rate of 3 °C/min) up to 246 °C, was chosen to ensure the detection and quantification of all molecules contained in the essential oil. The injector and the detector temperatures were set at 250 °C. The ionization energy was 70 eV. The sample injection volume was 1  $\mu$ L with the split mode (1:50). The flow rate of the helium gas used as mobile phase was 1.5 mL/min. The injector and detector temperatures were set at 250 °C. The retention indices of the separated molecules was measures and compared with that of standards of *n*-alkane mixtures (C8–C20) and mass spectral data of each peak using a computer library (Wiley-14 and NIST-14 Mass Spectral Library). Obtained data have been compared with those already reported in the literature<sup>38</sup>.

#### Antimicrobial activity measurement

#### Tested microorganisms

The antimicrobial activity of the essential oil was tested against 11 microorganisms provided by Iran Science and Technology Research Organization (IROST) and including seven Gram-negative bacteria, *Klebsiella pneumonia* (*K. pneumonia*, ATCC 10031), *Escherichia coli* (*E. coli*, ATCC 25922), *Pseudomonas aeruginosa* (*P. aeruginosa*, ATCC 27853), *Salmonella paratyphi-A serotype* (*S. paratyphi-A serotype*, ATCC 5702), *Shigella dysenteriae* (*S. dysenteriae*, PTCC 1188), *Acinetobacter baumannii* (*A. baumannii*, ATCC BAA-747), and *Proteus mirabilis* (*P. mirabilis*, ATCC 43071); three Gram-positive bacteria, *Staphylococcus epidermidis* (*S. epidermidis*, CIP 81.55), *Staphylococcus aureus* (*S. aureus*, ATCC 29737), and *Bacillus subtilis* (*B. subtilis*, ATCC 6633); and *Candida albicans* as yeast strain (*C. albicans*, ATCC 10231). Bacterial strains were cultured in Mueller-Hinton Agar growth medium and yeast in Sabouraud Dextrose Agar medium and incubated at 37 °C and 27 °C for 24 h, respectively.

#### Determination of inhibition halo by means of agar diffusion method

This method was performed based on CLSI standards<sup>39</sup>. Petri dishes of Mueller-Hinton Agar growth medium were used for the bacteria and Sabouraud Dextrose Agar medium for the yeast. Microbial suspensions were prepared for the different microbial variants and maintained for 24 h, with 0.5 McFarland turbidity. 100  $\mu$ L of each was cultured in the same growth media conditions. The essential oil was dissolved in dimethyl sulfoxide (60 mg/mL) and 10  $\mu$ L of obtained solution was poured into the petri dishes to reach a 600  $\mu$ g/mL of oil. Petri dishes were incubated at 37 °C for 24 h with bacterial strains and at 27 °C for 48 h with the yeast strain. The test was repeated three times for each essential oil sample and for each strain. The diameter of the inhibition halo was measured. Antibiotics gentamicin (10  $\mu$ g/disc) and rifampin (5  $\mu$ g/disc) for bacteria and nystatin (100,000 unit/mL) for yeast were used as standard drugs for positive control under the same test conditions.

#### Determination of the minimum inhibitory concentration (MIC)

The minimum concentration capable of inhibiting the growth of bacteria was assessed using the microdilution method. Essential oil (8000  $\mu$ g/mL) was dissolved in a mixture of tryptic soy broth and dimethyl sulfoxide and diluted to reach the following concentrations: 4000, 2000, 1000, 500, 250, 125, 62.5, 31.25 and 15.63  $\mu$ g/mL. Experiments were performed using 96-well microplates each filled with 95  $\mu$ L of culture medium, 5  $\mu$ L of bacterial suspension with 0.5 McFarland dilution and 100  $\mu$ L of each diluted essential oil were. The plates were incubated at 37 °C for 24 h using bacterial strains and for 48 and 72 h at 27 °C using yeast. After leaving them, the first concentration that inhibited the growth of different strains was considered as the minimum inhibitory concentration. For each strain, the test was repeated 3 times and 3 different samples of essential oil were used.

#### Determination of minimum bactericidal concentration (MBC)

To determine the minimum concentration able to kill the bacteria, the same microdilution method described above was used. The various bacteria strains were incubated for 24 h with the essential oil at different concentrations (8000, 4000, 2000, 1000, 500, 250, 125, 62.5, 31.25 and 15.63  $\mu$ g/mL). After 24 h of incubation with both bacteria and oils at different concentrations, 5  $\mu$ L of the content of each well was inoculated with nutrient agar medium and incubated at 37 °C for 24 h for bacterial strains. After incubation, the colony-forming units were enumerated. The MBC was the lowest concentration able to effectively reduce the growth of microorganisms (99.5%).

#### Statistical analysis

Analysis of variance (ANOVA) was performed to analyze the data. The difference between the mean values of the data was evaluated using Duncan's post hoc test at a significance level of 1%.

#### Results and discussion

#### Color and yield of essential oil

The essential oil extracted from *A. wilhelmsii* exhibited a distinct bluish-green color, unlike the predominantly yellow oils reported in previous studies<sup>36,40,41</sup>. This variance in color could be attributed to the specific harvesting time chosen for this study, as suggested by<sup>35</sup>. Their research indicated that the color of *A. wilhelmsii* essential oil varied with phenological stages, being yellow in May, colorless in June, and pale green in July. This highlights the influence of both phenological stage and habitat on the composition and color of the essential oil. The yield of essential oil obtained from *A. wilhelmsii* collected in the Maragheg area of the Kashan region, Iran, was approximately 0.1071% (w/w) based on the dry weight of plant material. This yield was notably lower than the highest reported yield of 2.47% obtained from plants cultivated in the Shahada Valley of West Azerbaijan province<sup>35</sup>. Such discrepancies in yield could be attributed to variations in habitat conditions across different Iranian regions. For instance, the yield of essential oil from plants collected in the natural habitat of Zanjan province<sup>42</sup>. Additionally<sup>11</sup>, observed decreasing yield values (from 5.6 to 1.1%) when *A. wilhelmsii* was cultivated in different regions of West Azerbaijan province. Similarly<sup>19</sup>, reported varying yields of essential oil (ranging from 0.6 to 0.3%) when obtained from *A. wilhelmsii* cultivated in Hamedan province. These findings underscore the significant influence of ecological characteristics on the yield of essential oil extracted from *A. wilhelmsii* across different habitat<sup>43,44</sup>.

#### Chemical compounds contained in the essential oil

The essential oil extracted from *A. wilhelmsii* revealed the presence of 55 different compounds, representing 100% of the oil composition (Table 1; Fig. 1). Comparatively<sup>42</sup>, identified 56 compounds in the essential oil of this plant, while other studies reported varying numbers of molecules. For instance<sup>36</sup>, identified 21 compounds<sup>11</sup>, found 26 compounds<sup>35</sup>, detected 33 compounds, and<sup>45</sup> identified 22 compounds. Studies conducted in Turkey reported the lowest number of molecules (16) when the plant was collected, while 46 compounds were isolated when collected from Anatolia<sup>33,46</sup>. This variability underscores the influence of growth habitat and environmental conditions on the composition of essential oil from *A. wilhelmsii*<sup>8</sup>. Among the compounds identified in the essential oil, oxygenated monoterpenes were the most abundant, comprising 47.87% of the oil. Fragranol emerged for the first time as the predominant terpene, constituting 33.22% of the oil. This contrasts with previous studies where fragranol content varied widely, ranging from 0.2 to 43.20%. Notably, fragranol is recognized for its unique cyclobutane ring structure and was firstly isolated from *Artemisia*<sup>47,48</sup>. Fragranyl acetate, detected at 16.18% in this study, was identified for the first time in *A. wilhelmsii* essential oil, along with oleic acid (6.33%), which was also newly detected. Oleic acid, an omega-9 unsaturated fatty acid, possesses various health-promoting properties including antioxidant, anti-inflammatory, and antimicrobial effects<sup>49,50</sup>. Additionally, α-pinene (3.61%), linalool (3.40%), and camphor (3.35%) were detected as less abundant compounds in the essential oil.

11. Hound, 3-methyl, acetate91808708.38.4C, μH <sub>0</sub> , C, μH <sub>0</sub> 20. Partner98029413.6C, μH <sub>0</sub> 4Delydroshhone10029500.2C, μH <sub>0</sub> 50. Parkner10159770.3C, μH <sub>0</sub> 7P.Prane10159700.3C, μH <sub>0</sub> 8Normal calcal10849700.3C, μH <sub>0</sub> 10Parkjabodyrate104010570.3C, μH <sub>0</sub> 11Isotoric calcalopentyleter104010570.3C, μH <sub>0</sub> 12a-Terpinen1084108410161.3C, μH <sub>0</sub> 13o-Symere108810151.3C, μH <sub>0</sub> 141.4-Calcalopentyleter108410161.0C, μH <sub>0</sub> 15y-Terpinen1168108410161.0C, μH <sub>0</sub> 141.4-Calcalopentyleter11681081.0C, μH <sub>0</sub> 15y-Terpinen116811681081.0C, μH <sub>0</sub> 16Isopentyl 2-methylonate116811681.0C, μH <sub>0</sub> 17iansolarate1168116811681.0C, μH <sub>0</sub> 18Iansolarate1169116811681.0C, μH <sub>0</sub> 19iansolarate1169116811681.0C, μH <sub>0</sub> 10iansolarate1169116811681.0C, μH <sub>0</sub> 10iansolarate116911681168<	No	Compound	RI Exp	RI Lit	Concentration (%)	Molecular formula				
2         all mane         947.         947.         947.         0.4         C.,H <sup>III</sup> ,           3         Camphene         1005.         950.         0.2         C.,H <sup>III</sup> ,           5         Benzaldehyde         1015.8         970.         0.3         C.,H <sup>III</sup> ,           6         a-shinene         1016.8         970.         0.2         C.,H <sup>III</sup> ,           7         β-Ince         1004.0         1083.0         970.         0.2         C.,H <sup>III</sup> ,           8         Yonogialchool         1083.0         1017.0         0.3         C.,H <sup>III</sup> ,           10         Patricacid acid         1004.0         1080.0         0.4         C.,H <sup>III</sup> ,           11         Iobatyric acid. iopentyleter         1005.7         107.0         0.3         C.,H <sup>III</sup> ,           12         al-Terpinen         1004.0         1005.0         101.0         C.,H <sup>III</sup> ,           13         i-Sectraid         1106.0         101.0         101.0         C.,H <sup>III</sup> ,           14         I-Sectraid         1106.0         101.0         C.,H <sup>III</sup> ,         C.,H <sup>III</sup> ,           14         I-Sectraid         1106.0         101.0         C.,H <sup>III</sup> ,         C.,H <sup>IIII</sup> ,	1	1-Butanol, 3-methyl-, acetate	918.9	876	0.3	C <sub>7</sub> H <sub>14</sub> O <sub>2</sub>				
3         Campben         1002.         971         0.3         C <sub>m</sub> H <sub>m</sub> 4         Dehydroashinene         1006.         966         0.2         C <sub>m</sub> H <sub>m</sub> 6         a Sahinene         1015.         975         0.2         C <sub>m</sub> H <sub>m</sub> 7         PErner         1016.         979         0.2         C <sub>m</sub> H <sub>m</sub> 9         Batnoic acd         1083.         970         0.3         C <sub>m</sub> H <sub>m</sub> O           10         Pentryi isoburyate         1064.         1084.         1087         0.3         C <sub>m</sub> H <sub>m</sub> O           11         Isoburyate-acid isopentyl ester         1064.         1084.         1081.         C <sub>m</sub> H <sub>m</sub> O         C <sub>m</sub> H <sub>m</sub> O           12         a Terpinene         1160.         1062         0.3         C <sub>m</sub> H <sub>m</sub> O           13         o-Cymene         1160.         1062         1.3         C <sub>m</sub> H <sub>m</sub> O           14         Isocheric acid         11661.         1162         1.4         C <sub>m</sub> H <sub>m</sub> O           14         Isocheric acid         1162.         1162         1.4         C <sub>m</sub> H <sub>m</sub> O           15         Servetric acid         1163.         1162         1.4         C <sub>m</sub> H <sub>m</sub> O           14         Iso	2	a-Pinene	983.7	934	3.6	C <sub>10</sub> H <sub>16</sub>				
4         Delydrosihnene         100.2         95         0.2         C. μ.μ.           5         Rexaldelyde         1015.8         97         0.3         C. μ.μ.           7         Ø.Prener         103.4         97         0.2         C. μ.μ.           8         Tompi alchool         104.8         990         0.2         C. μ.μ.           10         Bottyrica cick         104.8         107         0.3         C. μ.μ.           11         Isoburytic acick, sopentylester         106.4         108         0.4         C. μ.μ.           12         α-Terpinen         100.5         107         0.3         C. μ.μ.           13         S-Terpinen         100.6         103         1.3         C. μ.μ.           14         Is-Cinecle cick         116.0         101         1.4         C. μ.μ.           15         y-Terpinen         116.0         101         1.4         C. μ.μ.           16         Isopentyl-cinethiol         116.0         1.1         1.1         1.1         1.1         1.1         1.1         1.1         1.1         1.1         1.1         1.1         1.1         1.1         1.1         1.1         1.1         1.1 <td>3</td> <td>Camphene</td> <td>1002.3</td> <td>951</td> <td>0.3</td> <td>C<sub>10</sub>H<sub>16</sub></td>	3	Camphene	1002.3	951	0.3	C <sub>10</sub> H <sub>16</sub>				
§         Beraldehyde         1015.8         975         0.2         C, H <sub>4</sub> O           6         arshinene         1035.6         979         0.3         C, H <sub>4</sub> O           8         Yemogi alchool         1081.8         979         0.2         C, H <sub>4</sub> O           9         Batanoic acid         1084.3         979         0.2         C, H <sub>4</sub> O           10         Pentyl boottyrate         1040.4         1057         0.3         C, H <sub>4</sub> O,           11         Isobutyrate acid, isopentyl ester         1067.4         1018         0.4         C, H <sub>4</sub> O,           12         arCprinene         1080.5         1017         0.3         C, H <sub>4</sub> O,           13         arCprinene         1160.6         1062         0.3         C, H <sub>4</sub> O,           14         IAS-Gronole         1180.8         1100         4.4         C, H <sub>4</sub> O,           14         Iasoiderata         1163.5         1100         4.4         C, H <sub>4</sub> O,           14         Iasoiderata         1163.8         1101         4.4         C, H <sub>4</sub> O,           14         Iasoiderata         1189.1         1142         0.3         C, H <sub>4</sub> O,           15         repreneni         1189.1	4	Dehydrosabinene	1006.2	956	0.2	C <sub>10</sub> H <sub>14</sub>				
6         a-shinene         10256         977         0.3         C <sub>µ</sub> H <sub>µ</sub> 7         β-Pinene         1014.         979         0.2         C <sub>µ</sub> H <sub>µ</sub> O           8         Yamogi akhool         1084.3         999         0.2         C <sub>µ</sub> H <sub>µ</sub> O           10         Pentyi isobutyrate         1064.0         1057         0.3         C <sub>µ</sub> H <sub>µ</sub> O           11         Isobutyrate         1067.4         1018         0.4         C <sub>µ</sub> H <sub>µ</sub> O           12         a-Terpinene         1007.4         1018         0.4         C <sub>µ</sub> H <sub>µ</sub> O           13         o-Cymene         1008.4         1015         1.3         C <sub>µ</sub> H <sub>µ</sub> O           14         1.8-Concol         1008.4         1010         0.4         C <sub>µ</sub> H <sub>µ</sub> O           15         y-Terpinene         116.6         102         0.3         C <sub>µ</sub> H <sub>µ</sub> O           15         y-Terpinene         116.0         1062         0.3         C <sub>µ</sub> H <sub>µ</sub> O           14         Isocontracid         1168         1101         0.4         C <sub>µ</sub> H <sub>µ</sub> O           14         Isocontracid         11694         0.3         C <sub>µ</sub> H <sub>µ</sub> O           23         d-Verthone         1207.8         1122         0.4 <t< td=""><td>5</td><td>Benzaldehyde</td><td>1015.8</td><td>975</td><td>0.2</td><td>C<sub>7</sub>H<sub>6</sub>O</td></t<>	5	Benzaldehyde	1015.8	975	0.2	C <sub>7</sub> H <sub>6</sub> O				
β-Pimene         1031.6         979         0.2         C <sub>μ</sub> H <sub>μ</sub> C           8         Yomogi alchool         1088.3         999         0.2         C <sub>μ</sub> H <sub>μ</sub> C           10         Pentyl isobutyrate         1064.0         1057         0.3         C <sub>μ</sub> H <sub>μ</sub> C           11         Isobutyria acidi, isopentyl ester         1067.4         1018         4.4         C <sub>μ</sub> H <sub>μ</sub> C           12         α-Terpinene         1055.7         107         0.3         C <sub>μ</sub> H <sub>μ</sub> C           13         botymir, acidi, isopentyl ester         1068.0         1051         1.3         C <sub>μ</sub> H <sub>μ</sub> C           14         1.4 C-fincole         1089.4         1031         2.1         C <sub>μ</sub> H <sub>μ</sub> C           14         1.8 Concole         1089.4         1031         2.1         C <sub>μ</sub> H <sub>μ</sub> C           15         γ-Terpinene         1166.0         1060         3.4         C <sub>μ</sub> H <sub>μ</sub> C           16         Isopentyle ancethe         1189.4         100         3.4         C <sub>μ</sub> H <sub>μ</sub> C           16         Isopentyle ancethe         1189.1         1142         0.3         C <sub>μ</sub> H <sub>μ</sub> C           12         trans-Achidran         128.4         1142         1.4         0.3         C <sub>μ</sub> H <sub>μ</sub> C           13	6	α-Sabinene	1025.6	977	0.3	C <sub>10</sub> H <sub>16</sub>				
8         Yomogi alchool         1048.3         999         0.2         C <sub>μ</sub> , H <sub>μ</sub> O,           9         Butanoic acid         1082         107         0.3         C, H <sub>μ</sub> O,           11         loebutyric acid, isopentyl ester         10640         1088         0.4         C, H <sub>μ</sub> O,           12         al-Terpinene         1055.7         107         0.3         C, H <sub>μ</sub> O           13         o-Cymene         1080.8         1010         0.4         C, H <sub>μ</sub> O           14         1.8-Cincole         1080.4         1010         0.4         C, H <sub>μ</sub> O           15         'Perpinene         1160.8         1100         0.4         C, H <sub>μ</sub> O           15         Inano         1163.8         1100         0.4         C, H <sub>μ</sub> O           16         Isoveneric acid         1163.8         1100         0.4         C, H <sub>μ</sub> O           17         Inanoo         1164.8         1160         1.4         C, H <sub>μ</sub> O           20         e-trepinen-tentioi         1163.9         1.14         1.12         C, H <sub>μ</sub> O           21         Crayanherone         1223         1.145         3.3         C, H <sub>μ</sub> O           22         transe-tenthoi         1224	7	β-Pinene	1031.6	979	0.2	C <sub>10</sub> H <sub>16</sub>				
9         Batanoic acid         10582         107         0.3         C <sub>4</sub> H <sub>4</sub> O <sub>2</sub> 10         Penyli siobutyrate         10640         1057         0.3         C <sub>2</sub> H <sub>4</sub> O           11         Isobutyrate cald, isopenyl exter         10674         1018         0.4         C <sub>4</sub> H <sub>4</sub> O           12         a Terpinene         10674         10857         1017         0.3         C <sub>4</sub> H <sub>4</sub> O           13         o-Cymene         10804         1015         1.3         C <sub>4</sub> H <sub>4</sub> O           14         1.8 -Cincole         10804         1002         0.3         C <sub>4</sub> H <sub>4</sub> O           15         y-Terpinene         1166.0         1002         0.4         C <sub>4</sub> H <sub>4</sub> O           16         Isopenyl 2-methylbutanoate         1163.0         1105         0.5         C <sub>6</sub> H <sub>4</sub> O <sub>2</sub> O           17         Linalool         1163.0         1108         0.4         C <sub>6</sub> H <sub>4</sub> O         0.3         C <sub>6</sub> H <sub>4</sub> O           10         Aunyl isovalerate         1165.0         1108         0.4         1.1         C <sub>6</sub> H <sub>6</sub> O           12         trans-2-Menthenol         1224.1         1454         0.3         C <sub>6</sub> H <sub>6</sub> O           12         trans-2-Menthenol         1224.1         1454	8	Yomogi alchool	1048.3	999	0.2	C <sub>10</sub> H <sub>18</sub> O				
10       Pentyl isobutyriate       1064.0       1057       0.3 $C_yH_yO_y$ 11       Isobutyria cicil, isopentyl ester       10057.4       1018       0.4 $C_yH_yO_y$ 12       a-Terpinene       10057.4       1018       0.3 $C_wH_yO_y$ 13       a-Cymene       10808.4       1031       2.1 $C_wH_yO_y$ 14       1.8-Cincole       1089.4       1010       0.4 $C_wH_yO_yO_yO_yO_yO_yO_yO_yO_yO_yO_yO_yO_yO_$	9	Butanoic acid	1058.2	1017	0.3	C <sub>9</sub> H <sub>18</sub> O <sub>2</sub>				
11       Isobutyric acid, isopentyl ester       1067.4       1018       0.4 $C_{ij}H_{ijk}O_j$ 12       a "Erpinene       1005.7       1017       0.3 $C_{ijj}H_{ijk}$ 13       o-Cymene       1008.8       1015       1.3 $C_{ijj}H_{ijk}$ 14       1.8-Cincole       1089.8       1011       0.1 $C_{ijj}H_{ijk}$ 15       Y-Terpinene       1116.0       1062       0.3 $C_{ijj}H_{ijk}$ 15       hypentyl 2-methylbutanoate       1163.8       1100       0.4 $C_{ijjk}H_{ijk}$ 18       isovaleric acid       1163.7       1108       0.7 $C_{ijk}H_{ijk}$ 21       Crysanthenone       1184.1       1125       0.3 $C_{ijk}H_{ijk}$ 22       trans-2-Menthenol       1189.1       1142       0.7 $C_{ijk}H_{ijk}$ 23       cis-Verbenol       1207.8       1140       1.1 $C_{ijk}H_{ijk}$ $C_{ijk}H_{ijk}$ 24       Camphor       1212.3       1145       3.3 $C_{ijk}H_{ijk}$ 25       Dill eher - Anethoruran       1216.8       1191.2       0.8 $C_{ijk}H_{ijk}$ 26       a-Pinocarvone	10	Pentyl isobutyrate	1064.0	1057	0.3	C <sub>9</sub> H <sub>18</sub> O <sub>2</sub>				
12       a-Terpinene       1055.7       1017       0.3 $C_{10}H_{16}$ 13       o-Cymene       1080.8       1035       1.3 $C_{10}H_{10}$ 14       1.8-Cincole       1089.4       1031       2.1 $C_{10}H_{10}$ 15       y-Terpinene       11161.0       1062       0.3 $C_{10}H_{10}$ 16       Isopentyl2-methylbutanoate       1156.8       1100       0.4 $C_{10}H_{10}$ 17       Linalood       1163.8       1105       0.5 $C_{10}H_{10}$ 18       Isovaleria cicl       1165.9       1108       0.7 $C_{10}H_{10}$ 20       4.sopropylbenzentbiol       1184.1       1122       0.3 $C_{10}H_{10}$ 21       Crysanthenone       1212.3       1140       1.1 $C_{10}H_{10}$ 22       trans-2-Menthenol       1212.3       1142       0.3 $C_{10}H_{10}$ 23       cs-Verbenol       1223.5       1       1.2 $C_{10}H_{10}$ 24       Camphor       1212.3       145       3.3 $C_{10}H_{10}$ 25       Dill ether - Anethofuran       1212.4       1145       0.4 $C_{10}H_{1$	11	Isobutyric acid, isopentyl ester	1067.4	1018	0.4	C <sub>9</sub> H <sub>18</sub> O <sub>2</sub>				
13       o-Cymene       1080.8       1015       1.3 $C_{10}H_{10}$ 14       1.8 - Cincole       1099.4       1031       2.1 $C_{00}H_{10}$ 15       Y-Terpinene       1116.0       1060       0.3 $C_{00}H_{10}O_{10}$ 15       ispent/2-methylbutanoate       1156.8       1101       0.4 $C_{00}H_{10}O_{10}$ 17       Inalool       1160.8       1100       3.4 $C_{10}H_{10}O_{10}$ 18       Isovaleria caid       1163.7       1105       0.5 $C_{00}H_{20}O_{10}$ 24       4-Isoporpylbezzenethiol       1169.4       -       0.3 $C_{10}H_{10}O_{10}$ 21       Crysanthenone       1121.3       1142       0.7 $C_{00}H_{10}O_{10}$ 23       civ-Verbenol       1222.3       1140       1.1 $C_{10}H_{10}O_{10}$ 24       Camphor       1212.3       1145       3.3 $C_{00}H_{10}O_{10}$ 25       Dil ether = Anethofuran       1212.8       1164.2       0.3 $C_{10}H_{10}O_{10}$ 26       e-Pinocarvone       1228.4       1164.2       0.3 $C_{00}H_{10}O_{10}$ 26       ispine-4-ol       1235.9	12	α-Terpinene	1055.7	1017	0.3	C <sub>10</sub> H <sub>16</sub>				
14       1.8-Cincole       1089.4       1031       2.1 $C_{10}H_{10}O$ 15       y-Terpinene       1116.0       1062       0.3 $C_{00}H_{20}O_{1}$ 16       lsopentyl 2-methylbutanoate       1156.8       1100       0.4 $C_{10}H_{20}O_{1}$ 18       lsovaleric acid       1163.7       1108       0.7 $C_{10}H_{20}O_{1}$ 20       4-lsoperyblezenethiol       1169.4       -       0.3 $C_{11}H_{20}O_{1}$ 21       Crysanthenone       1184.1       1125       0.3 $C_{10}H_{10}O_{1}$ 22       trans-2-Menthenol       1184.1       1142       0.7 $C_{10}H_{10}O_{1}$ 22       trans-2-Menthenol       1184.1       1145       0.3 $C_{00}H_{10}O_{1}$ 23       cis-Verbenol       1207.8       1145       1.3 $C_{00}H_{10}O_{1}$ 24       Campbor       1212.3       1145       0.3 $C_{00}H_{10}O_{1}$ 25       Dill ether = Anethofuran       1216.8       1174       0.8 $C_{00}H_{10}O_{1}$ 26       a-Pinocarrone       1228.4       1140       1.4 $C_{10}O_{1}O_{1}$ 27       Cyclobexenc4-methylene	13	o-Cymene	1080.8	1015	1.3	C <sub>10</sub> H <sub>14</sub>				
15 $\gamma$ -Terpinene       1116.0       1062       0.3 $C_{10}$ H <sub>16</sub> 16       Isopentyl 2-methylbutanoate       1156.8       1101       0.4 $C_{10}$ H <sub>10</sub> O,         17       Linalool       1160.8       1100       3.4 $C_{10}$ H <sub>10</sub> O,         18       Isovaleric acid       1163.7       1105       0.5 $C_{10}$ H <sub>20</sub> O,         20       4-Isopropylbenzmethiol       1169.4       -       0.3 $C_{10}$ H <sub>20</sub> O,         21       Crysanthenone       1184.1       1125       0.3 $C_{10}$ H <sub>10</sub> O         23       cis-Verbenol       1207.8       1140       1.1 $C_{10}$ H <sub>10</sub> O         24       Camphor       1212.3       1145       3.3 $C_{10}$ H <sub>10</sub> O         25       Dill ether = Anethofuran       1216.8       1191.2       0.8 $C_{10}$ H <sub>10</sub> O         26 $\alpha$ -Pinocarvone       1224.4       1174       0.8 $C_{10}$ H <sub>10</sub> O         26 $\alpha$ -Pinocarvone       1284.8       1178       0.8 $C_{10}$ H <sub>10</sub> O         27       Cyclohexene4-methylene       1251.9       -       0.3 $C_{10}$ H <sub>10</sub> O         28       iscyrpined       1264.4       1191       0.8	14	1,8-Cineole	1089.4	1031	2.1	C <sub>10</sub> H <sub>18</sub> O				
16       Isopentyl 2-methylbutanoate       1156.8       1101       0.4 $C_{10}^{11}H_{20}O_{2}^{11}$ 17       Linalool       1160.8       1100       3.4 $C_{10}H_{20}O_{2}^{11}$ 18       Isovaleric acid       1163.7       1105       0.5 $C_{10}H_{20}O_{2}^{11}$ 20       4-Isopropylbenzenethiol       1169.4       -       0.3 $C_{10}H_{10}O_{11}^{11}O_{1}^{11}O_{1}^{1$	15	γ-Terpinene	1116.0	1062	0.3	C <sub>10</sub> H <sub>16</sub>				
17       Linalool       1160.8       1100       3.4 $C_{10}H_{10}O$ 18       Isovaleric acid       1163.7       1105       0.5 $C_{10}H_{20}O_2$ 19       Amyl isovalerate       1165.9       1108       0.7 $C_{10}H_{20}O_2$ 20       4-Isopropylbenznethiol       1169.4       -       0.3 $C_{10}H_{10}O$ 21       Crysanthenone       1184.1       1125       0.3 $C_{10}H_{10}O$ 22       trans-2-Menthenol       1189.1       1142       0.7 $C_{10}H_{10}O$ 22       tars-2-Menthenol       1207.8       1140       1.1 $C_{10}H_{10}O$ 23       cis/Verbenol       1212.8       1142       0.8 $C_{10}H_{10}O$ 24       Camphor       1228.4       1164.2       0.3 $C_{10}H_{10}O$ 25       Dill ether = Anethofuran       1248.8       1178       0.8 $C_{10}H_{10}O$ 27       Cyclobexnet-4-methylene       1239.5       -       0.5 $C_{10}H_{10}O$ 30       a.Terpinenol       1264.4       1191       0.8 $C_{10}H_{10}O$ 31       Fargaroni doctato       1272       -       0	16	Isopentyl 2-methylbutanoate	1156.8	1101	0.4	C <sub>10</sub> H <sub>20</sub> O <sub>2</sub>				
18       Isovaleria caid       11637       1105       0.5 $C_{10}H_{20}O_2$ 19       Amyl isovalerate       11659       1108       0.7 $C_{10}H_{20}O_2$ 20       4-Isopropylbenzenethiol       11694       -       0.3 $C_{10}H_{40}O_2$ 21       Crysanthenone       11841       1125       0.3 $C_{10}H_{40}O$ 23       its-Verbenol       12078       1140       1.1 $C_{10}H_{10}O$ 24       Camphor       1212.3       1145       3.3 $C_{10}H_{10}O$ 25       Dill ether = Anethofuran       12168       11122       0.8 $C_{10}H_{10}O$ 26 $\alpha$ -Pinocarvone       12284       11712       0.8 $C_{10}H_{10}O$ 26 $\alpha$ -Pinocarvone       12848       1178       0.8 $C_{10}H_{10}O$ 27       Cyclohexen-4-methylene       12912       -       0.3 $C_{10}H_{10}O$ 38       Terpinen-4-ol       1248.8       1178       0.8 $C_{10}H_{10}O$ 30 $\alpha$ -Terpineol       1264.4       1191       0.8 $C_{10}H_{10}O$ 31       Fragranyl acetate       1327.4       1345	17	Linalool	1160.8	1100	3.4	C <sub>10</sub> H <sub>18</sub> O				
19       Amyl isovalerate       1165.9       1108 $0.7$ $C_{1\mu}H_{30}O_{2}$ 20       4-Isopropylbezcenthiol       1169.4       - $0.3$ $C_{1\mu}H_{3}O$ 21       Crysanthenone       1184.1       112 $0.3$ $C_{1\mu}H_{3}O$ 23       cis-Verbenol       1184.1       1142 $0.7$ $C_{1\mu}H_{10}O$ 23       cis-Verbenol       1212.3       1145 $3.3$ $C_{1\mu}H_{10}O$ 24       Camphor       1212.3       1145 $3.3$ $C_{1\mu}H_{10}O$ 25       Dill ether = Anethofuran       1216.8       1191.2 $0.8$ $C_{1\mu}H_{10}O$ 26       e-Proncorvone       1228.4       1164.2 $0.3$ $C_{1\mu}H_{10}O$ 27       Cyclohexne4-methylene       1239.5       - $0.5$ $C_{1\mu}H_{10}O$ 28       IEprinen4-ol       1248.8       1178 $0.8$ $C_{1\mu}H_{10}O$ 30       a-Terpineol       1264.4       1191 $0.8$ $C_{1\mu}H_{10}O$ 31       Fragrand       1257.2       - $0.3$ $C_{1\mu}H_{10}O$ 32       Bicyclo[10.1.0]tridec-1-ene       1397.7	18	Isovaleric acid	1163.7	1105	0.5	C <sub>10</sub> H <sub>20</sub> O <sub>2</sub>				
20       4-Isopropylbenzenethiol       1169.4       -       0.3 $C_yH_yS$ 21       Crysanthenone       1184.1       1125       0.3 $C_{yH}H_yO$ 21       trans-2-Menthenol       1189.1       1142       0.7 $C_{yH}H_yO$ 23       ds-Verbenol       1207.8       1140       1.1 $C_{yH}H_yO$ 24       Camphor       1212.3       1145       3.3 $C_{yH}H_yO$ 25       Dill ether = Anethofuran       1216.8       1191.2       0.8 $C_{yH}H_yO$ 26       a-Pinocarvone       1228.4       1164.2       0.3 $C_{yH}H_yO$ 27       Cyclohexene,4-methylene       1239.5       -       1.2 $C_{yH}H_yO$ 28       Terpinen-4-0       1284.8       1178       0.8 $C_{yH}H_yO$ 30       a-Terpineol       1264.4       1191       0.8 $C_{10}H_{10}O$ 31       Fragranol       1288.6       1221.6       33.2 $C_{xH}H_yO$ 33       Fragranol       1284.6       1244       139.7 $C_{xH}H_yO$ 34       Thymol       1368.6       1294       0.3 $C_{xH}H_yO$ <t< td=""><td>19</td><td>Amyl isovalerate</td><td>1165.9</td><td>1108</td><td>0.7</td><td>C<sub>10</sub>H<sub>20</sub>O<sub>2</sub></td></t<>	19	Amyl isovalerate	1165.9	1108	0.7	C <sub>10</sub> H <sub>20</sub> O <sub>2</sub>				
21       Crysanthenone       1184.1       1125       0.3 $C_{1p}H_{1k}O$ 22       trans-2-Menthenol       1189.1       1142       0.7 $C_{1p}H_{1k}O$ 23       dis-Verbenol       1207.8       1140       1.1 $C_{1p}H_{1k}O$ 24       Camphor       1212.3       1145       3.3 $C_{1p}H_{1k}O$ 24       Camphor       1212.4       1164.2       0.8 $C_{1p}H_{1k}O$ 25       Dill eher = Anethofuran       1216.8       1191.2       0.8 $C_{1p}H_{1k}O$ 26       a-Pinocarvone       1228.4       1164.2       0.3 $C_{1p}H_{1k}O$ 29       (3E)-3.7-dimethylocta-3.6-dien-1-ol       1281.6       1191.0       0.8 $C_{1p}H_{1k}O$ 30       a-Frepineol       1284.6       1221.6       332 $C_{1p}H_{1k}O$ 31       Fragrand       1284.6       1241.6       132.5 $C_{1n}H_{1k}O$ 32       Bicyclo[10.1.0]tridec-1-ene       1297.2       -       0.3 $C_{1p}H_{2O}O$ 33       Fragranyl acetate       1327.4       1345       16.2 $C_{1n}H_{2O}O$ 34       Thymol       1366.6       1294	20	4-Isopropylbenzenethiol	1169.4	-	0.3	C <sub>9</sub> H <sub>12</sub> S				
22       trans-2-Menthenol       1189.1       1142       0.7 $C_{10}H_{16}O$ 23       cis-Verbenol       1207.8       1140       1.1 $C_{10}H_{16}O$ 24       Camphor       1212.3       1145       3.3 $C_{10}H_{16}O$ 25       Dill ether = Anethofuran       1216.8       1191.2       0.8 $C_{10}H_{16}O$ 26       a-Pincoarvone       1228.4       1164.2       0.3 $C_{10}H_{10}O$ 27       Cyclohexene,4-methylene       1239.5       -       1.2 $C_{7}H_{10}O$ 28       Terpinen-4-ol       1248.8       1178       0.8 $C_{10}H_{10}O$ 30       a-Terpineol       1264.4       1191       0.8 $C_{10}H_{10}O$ 31       Fragranol       1288.6       1221.6       33.2 $C_{10}H_{10}O$ 33       Fragranol       1384.6       1244.0       0.3 $C_{11}H_{2}O$ 34       Thymol       1388.6       124       0.3 $C_{11}H_{2}O$ 35       Myrtenyl acetate       1393.7       1353       0.6 $C_{11}H_{2}O$ 36       Garanyl acetate       1474.1       1383       0.3 $C_$	21	Crysanthenone	1184.1	1125	0.3	C <sub>10</sub> H <sub>14</sub> O				
23       cis-Verbenol       1207.8       1140       1.1 $C_{10}H_{16}O$ 24       Camphor       1212.3       1145       3.3 $C_{10}H_{16}O$ 25       Dill ether = Anethofuran       1216.8       1191.2       0.8 $C_{00}H_{16}O$ 26       a-Pinocarvone       1228.4       1178       0.8 $C_{10}H_{16}O$ 27       Cyclohexen-4-methylene       1239.5       -       1.2 $C_{710}$ 28       Terpinen-4-ol       1248.8       1178       0.8 $C_{10}H_{18}O$ 30       a-Terpineol       1264.4       191       0.8 $C_{10}H_{18}O$ 31       Fragranol       1288.6       1221.6       33.2 $C_{10}H_{18}O$ 32       Bicyclo[10.10]tridec-1-ene       1297.2       -       0.3 $C_{12}H_{20}O_2$ 33       Fragranyl acetate       1393.7       1335       0.6 $C_{12}H_{20}O_2$ 34       Thymol       1388.6       1244       0.3 $C_{11}H_{20}O_2$ 35       Myrtenyl acetate       1393.7       1335       0.6 $C_{12}H_{30}O_2$ 36       Geranyl acetate       1417.4       188.3       0.3 <td>22</td> <td>trans-2-Menthenol</td> <td>1189.1</td> <td>1142</td> <td>0.7</td> <td>C<sub>10</sub>H<sub>18</sub>O</td>	22	trans-2-Menthenol	1189.1	1142	0.7	C <sub>10</sub> H <sub>18</sub> O				
24       Camphor       1212.3       1145       3.3 $C_{10}H_{16}O$ 25       Dill ether = Anethofuran       1216.8       1191.2       0.8 $C_{10}H_{16}O$ 26       a-Pinocarvone       1228.4       1164.2       0.3 $C_{10}H_{16}O$ 27       Cyclohexene,4-methylene       1239.5       -       1.2 $C_{7}H_{10}O$ 28       Terpinen-4-ol       1248.8       1178       0.8 $C_{10}H_{18}O$ 30       a-Terpined       1251.9       -       0.5 $C_{10}H_{18}O$ 30       a-Terpineol       1272.       -       0.3 $C_{10}H_{18}O$ 31       Fragranol       1288.6       121.6       33.2 $C_{10}H_{18}O$ 32       Bicyclo[10.1.0]tridec-1-ene       1297.2       -       0.3 $C_{10}H_{10}O$ 33       Fragranyl acetate       1327.4       1355       16.2 $C_{11}H_{20}O_2$ 34       Thymol       1386.6       1244       0.3 $C_{10}H_{10}O$ 35       Myrtenyl acetate       1393.7       1355       0.6 $C_{11}H_{10}O$ 36       Geranyl acetate       1407.4       1830       0.3	23	cis-Verbenol	1207.8	1140	1.1	C <sub>10</sub> H <sub>16</sub> O				
25       Dil detr = Anethofuran       1216.8       1191.2       0.8 $C_{10}H_{4}O$ 26       a-Pinocarvone       1228.4       1164.2       0.3 $C_{10}H_{4}O$ 27       Cyclobexene,4-methylene       1239.5       -       1.2 $C_{7}H_{10}O$ 28       Terpinen-4-ol       1248.8       1178       0.8 $C_{10}H_{40}O$ 29       (3E)-3,7-dimethylocta-3,6-dien-1-ol       1251.9       -       0.5 $C_{10}H_{40}O$ 30       a-Terpineol       1264.4       1191       0.8 $C_{10}H_{40}O$ 31       Fragranol       1288.6       1221.6       33.2 $C_{10}H_{40}O$ 32       Bicyclo[10.1.0]tridec-1-ene       1297.2       -       0.3 $C_{12}H_{20}O_2$ 33       Fragranol       1368.6       1294       0.3 $C_{12}H_{20}O_2$ 34       Thymol       1368.6       1294       0.3 $C_{12}H_{20}O_2$ 34       Thymol       1368.6       1294       0.3 $C_{12}H_{20}O_2$ 35       Myrtenyl acetate       1393.7       1335       0.6 $C_{12}H_{20}O_2$ 36       Garanyl acetate       1410.1       14839 <td>24</td> <td>Camphor</td> <td>1212.3</td> <td>1145</td> <td>3.3</td> <td>C<sub>10</sub>H<sub>16</sub>O</td>	24	Camphor	1212.3	1145	3.3	C <sub>10</sub> H <sub>16</sub> O				
26       a-Pinocarvone       1228.4       1164.2       0.3 $C_{10}H_{10}Q$ 27       Cyclohexene,4-methylene       1239.5       -       1.2 $C_{10}H_{18}Q$ 28       Terpinen-4-ol       1248.8       1178       0.8 $C_{10}H_{18}Q$ 29       (3E)-3,7-dimethylocta-3,6-dien-1-ol       1251.9       -       0.5 $C_{10}H_{18}Q$ 30       a-Terpineol       1264.4       1191       0.8 $C_{10}H_{18}Q$ 31       Fragranol       1286.6       1221.6       33.2 $C_{10}H_{18}Q$ 32       Bicyclo[10.10]tridec-1-ene       1297.2       -       0.3 $C_{12}H_{20}Q_2$ 34       Thymol       1368.6       1294       0.3 $C_{10}H_{10}Q$ 35       Myrtenyl acetate       1393.7       1335       0.6 $C_{12}H_{10}Q_2$ 36       Geranyl acetate       1417.4       1383       0.3 $C_{12}H_{20}Q_2$ 37       Jasmone       1468.6       1406       0.3 $C_{12}H_{10}Q_2$ 37       Jasmone       1453.9       1.6 $C_{12}H_{24}Q_2$ 40       Fragranyl 2-methylbutyrate       1557.4       1483.9       1.6	25	Dill ether = Anethofuran	1216.8	1191.2	0.8	C <sub>10</sub> H <sub>16</sub> O				
27       Cyclohexene,4-methylene       1239.5       -       1.2 $C_{H_{10}}$ 28       Terpinen-4-ol       1248.8       1178       0.8 $C_{10}H_{18}O$ 29       (3E)-3.7-dimethylocta-3.6-dien-1-ol       1251.9       -       0.5 $C_{10}H_{18}O$ 30       a-Terpineol       1264.4       1191       0.8 $C_{10}H_{18}O$ 31       Fragranol       1286.6       1221.6       3.2.2 $C_{10}H_{18}O$ 32       Bicyclo[10.1.0]tridec-1-ene       1297.2       -       0.3 $C_{12}H_{20}O_2$ 34       Thymol       1368.6       1294       0.3 $C_{10}H_{16}O$ 35       Myrtenyl acetate       1393.7       1335       0.6 $C_{12}H_{20}O_2$ 36       Geranyl acetate       1417.4       1383       0.3 $C_{12}H_{20}O_2$ 37       Jasmone       1468.6       1406       0.3 $C_{11}H_{10}O$ 38       Caryophyllene       1500.1       1423       0.2 $C_{13}H_2$ 39       Fragranyl 2-methylbutyrate       1519.1       157.4       148.9       1.6 $C_{15}H_2$ 40       Fragranyl isobutyrate       154.9<	26	a-Pinocarvone	1228.4	1164.2	0.3	C <sub>10</sub> H <sub>14</sub> O				
28       Terpinen 4-ol       1248.8       1178       0.8 $C_{10}H_{18}O$ 29       (3E)-3,7-dimethylocta-3,6-dien-1-ol       1251.9       -       0.5 $C_{10}H_{18}O$ 30       a-Terpineol       1264.4       1191       0.8 $C_{10}H_{18}O$ 31       Fragranol       1288.6       1221.6       33.2 $C_{10}H_{18}O$ 32       Bicyclo[10.1.0]tridec-1-ene       1297.2       -       0.3 $C_{11}H_{20}O_2$ 33       Fragranyl acetate       1327.4       1345       16.2 $C_{11}H_{20}O_2$ 34       Thymol       1368.6       1294       0.3 $C_{10}H_{18}O_2$ 36       Geranyl acetate       1393.7       1335       0.6 $C_{12}H_{18}O_2$ 36       Garanyl acetate       1417.4       1383       0.3 $C_{12}H_{18}O_2$ 38       Caryophyllene       1500.1       1423       0.2 $C_{13}H_{20}O_2$ 39       Fragranyl 2-methylbutyrate       1519.4       1483.9       1.6 $C_{14}H_{20}O_2$ 41       Germacrene D       1564.9       1485       1.6 $C_{13}H_{20}O_2$ 41       Germacrene D       1564.9	27	Cyclohexene,4-methylene	1239.5	-	1.2	C <sub>7</sub> H <sub>10</sub>				
29       (3E)-3,7-dimethylocta-3,6-dien-1-ol       1251.9       -       0.5 $C_{10}H_{18}O$ 30       a-Terpineol       1264.4       1191       0.8 $C_{10}H_{18}O$ 31       Fragranol       1288.6       1221.6       33.2 $C_{10}H_{18}O$ 32       Bicyclo[10.1.0]tridec-1-ene       1297.2       -       0.3 $C_{13}H_{22}$ 33       Fragranyl acetate       1327.4       1345       16.2 $C_{11}H_{20}O_{2}$ 34       Thymol       1368.6       1294       0.3 $C_{10}H_{18}O_{2}$ 36       Geranyl acetate       1393.7       1335       0.6 $C_{12}H_{20}O_{2}$ 37       Jasmone       1468.6       1406       0.3 $C_{11}H_{20}O_{2}$ 38       Caryophyllene       1500.1       1423       0.2 $C_{12}H_{20}O_{2}$ 40       Fragranyl 2-methylbutyrate       1519       154.9       148       1.6 $C_{11}H_{20}O_{2}$ 41       Germacrene D       1564.9       1485       1.6 $C_{12}H_{20}O_{2}$ 41       Germacrene D       1564.9       1485       1.6 $C_{12}H_{20}O_{2}$ 42       Sesquicincole	28	Terpinen-4-ol	1248.8	1178	0.8	C <sub>10</sub> H <sub>18</sub> O				
30       a-Terpineol       1264.4       1191       0.8 $C_{10}H_{18}O$ 31       Fragranol       1288.6       1221.6       33.2 $C_{13}H_{22}$ 33       Fragranyl acetate       1327.4       1345       16.2 $C_{12}H_{20}O_2$ 34       Thymol       1368.6       1294       0.3 $C_{10}H_{14}O$ 35       Myrtenyl acetate       1393.7       1335       0.6 $C_{12}H_{20}O_2$ 36       Geranyl acetate       1417.4       1383       0.3 $C_{12}H_{20}O_2$ 37       Jasmone       1468.6       1406       0.3 $C_{11}H_{16}O$ 38       Caryophyllene       1500.1       1423       0.2 $C_{13}H_{24}$ 39       Fragranyl 2-methylbutyrate       1511.9       1574.9       3.2 $C_{13}H_{26}O_2$ 41       Germacrene D       1564.9       1485       1.6 $C_{13}H_{26}O_2$ 42       Sequicincole       1594.3       1515       0.8 $C_{13}H_{26}O_2$ 43       Nerolidol       1642.9       1565       1.8 $C_{13}H_{26}O_2$ 44       (Z,E)-a-Farnesene       1662.6       1491       0.2	29	(3E)-3,7-dimethylocta-3,6-dien-1-ol	1251.9	-	0.5	C <sub>10</sub> H <sub>18</sub> O				
Tag       Tag       Tag       Tag       Tag       Tag       Tag       Tag         31       Fragranol       1288.6       1221.6       33.2 $C_{13}H_{22}$ 33       Fragranyl acetate       1327.4       1345       16.2 $C_{12}H_{20}O_2$ 34       Thymol       1368.6       1294       0.3 $C_{10}H_{14}O$ 35       Myrtenyl acetate       1393.7       1335       0.6 $C_{12}H_{20}O_2$ 36       Geranyl acetate       1417.4       1383       0.3 $C_{12}H_{20}O_2$ 37       Jasmone       1468.6       1406       0.3 $C_{11}H_{20}O_2$ 38       Caryophyllene       1500.1       1423       0.2 $C_{13}H_{20}O_2$ 39       Fragranyl 2-methylbutyrate       151.9       157.4       148.9       1.6 $C_{14}H_{20}O_2$ 40       Fragranyl isobutyrate       1557.4       148.9       1.6 $C_{13}H_{20}O_2$ 41       Germacrene D       1564.9       1485       1.6 $C_{13}H_{20}O_2$ 42       Sesquicineole       157.4       148.9       1.6 $C_{13}H_{20}O_2$ 44       (Z,E)-a-Farnesene <td< td=""><td>30</td><td>a-Terpineol</td><td>1264.4</td><td>1191</td><td>0.8</td><td>C<sub>10</sub>H<sub>18</sub>O</td></td<>	30	a-Terpineol	1264.4	1191	0.8	C <sub>10</sub> H <sub>18</sub> O				
32       Bicyclo[10.1.0]tridec-1-ene       1297.2       -       0.3 $C_{13}H_{22}$ 33       Fragranyl acetate       1327.4       1345       16.2 $C_{12}H_{20}O_2$ 34       Thymol       1368.6       1294       0.3 $C_{10}H_{14}O$ 35       Myrtenyl acetate       1393.7       1335       0.6 $C_{12}H_{18}O_2$ 36       Geranyl acetate       1417.4       1383       0.3 $C_{12}H_{20}O_2$ 37       Jasmone       1468.6       1406       0.3 $C_{11}H_{16}O$ 38       Caryophyllene       1500.1       1423       0.2 $C_{15}H_{24}$ 39       Fragranyl 2-methylbutyrate       1511.9       1574.9       3.2 $C_{15}H_{26}O_2$ 40       Fragranyl isobutyrate       1557.4       1483.9       1.6 $C_{14}H_{26}O_2$ 41       Germacrene D       1564.9       1485       1.6 $C_{15}H_{24}$ 42       Sesquicincole       1594.3       1515       0.8 $C_{15}H_{26}O_2$ 43       Nerolidol       1642.9       1565       1.8 $C_{15}H_{26}O_2$ 44       (Z,E)-α-Farnesene       1662.6       1491 </td <td>31</td> <td>Fragranol</td> <td>1288.6</td> <td>1221.6</td> <td>33.2</td> <td>C<sub>10</sub>H<sub>18</sub>O</td>	31	Fragranol	1288.6	1221.6	33.2	C <sub>10</sub> H <sub>18</sub> O				
33       Fragranyl acetate       1327.4       1345       16.2 $C_{12}H_{19}O_2$ 34       Thymol       1368.6       1294       0.3 $C_{10}H_{14}O$ 35       Myrtenyl acetate       1393.7       1335       0.6 $C_{12}H_{18}O_2$ 36       Geranyl acetate       1417.4       1383       0.3 $C_{12}H_{20}O_2$ 37       Jasmone       1468.6       1406       0.3 $C_{11}H_{16}O$ 38       Caryophyllene       1500.1       1423       0.2 $C_{15}H_{24}$ 39       Fragranyl 2-methylbutyrate       1511.9       1574.9       3.2 $C_{15}H_{26}O_2$ 40       Fragranyl isobutyrate       1557.4       1483.9       1.6 $C_{14}H_{26}O_2$ 41       Germacrene D       1564.9       1485       1.6 $C_{15}H_{24}$ 42       Sesquicincole       1594.3       1515       0.8 $C_{15}H_{26}O$ 43       Nerolidol       1642.9       1565       1.8 $C_{15}H_{26}O$ 44       (Z,E)- $\alpha$ -Farnesene       1662.6       1491       0.2 $C_{15}H_{26}O$ 45       Caropohyllene oxide       1673.5       1589	32	Bicyclo[10.1.0]tridec-1-ene	1297.2	-	0.3	C <sub>13</sub> H <sub>22</sub>				
34       Thymol       1368.6       1294       0.3 $C_{10}B_{14}O$ 35       Myrtenyl acetate       1393.7       1335       0.6 $C_{12}H_{18}O_2$ 36       Geranyl acetate       1417.4       1383       0.3 $C_{12}H_{20}O_2$ 37       Jasmone       1468.6       1406       0.3 $C_{11}H_{16}O$ 38       Caryophyllene       1500.1       1423       0.2 $C_{13}H_{24}$ 39       Fragranyl 2-methylbutyrate       1511.9       1574.9       3.2 $C_{14}H_{26}O_2$ 40       Fragranyl isobutyrate       1557.4       1483.9       1.6 $C_{13}H_{24}$ 42       Sesquicincole       1594.3       1515       0.8 $C_{15}H_{26}O$ 43       Nerolidol       1642.9       1565       1.8 $C_{15}H_{24}O$ 45       Caryophyllene oxide       1673.5       1589       0.9 $C_{15}H_{26}O$ 44       (Z,E)- $\alpha$ -Farnesene       1662.6       1491       0.2 $C_{15}H_{26}O$ 45       Caryophyllene oxide       1673.5       1589       0.9 $C_{15}H_{26}O$ 46       Succinic acid, di(1-(pentafluorophenyl)ethyl) ester <t< td=""><td>33</td><td>Fragranyl acetate</td><td>1327.4</td><td>1345</td><td>16.2</td><td>C<sub>12</sub>H<sub>20</sub>O<sub>2</sub></td></t<>	33	Fragranyl acetate	1327.4	1345	16.2	C <sub>12</sub> H <sub>20</sub> O <sub>2</sub>				
35       Myrtenyl acetate       1393.7       1335       0.6 $C_{12}H_{18}O_2$ 36       Geranyl acetate       1417.4       1383       0.3 $C_{12}H_{20}O_2$ 37       Jasmone       1468.6       1406       0.3 $C_{11}H_{10}O$ 38       Caryophyllene       1500.1       1423       0.2 $C_{15}H_{24}$ 39       Fragranyl 2-methylbutyrate       1511.9       1574.9       3.2 $C_{15}H_{26}O_2$ 40       Fragranyl isobutyrate       1557.4       1483.9       1.6 $C_{15}H_{26}O_2$ 41       Germacrene D       1564.9       1485       1.6 $C_{15}H_{26}O_2$ 43       Nerolidol       1642.9       1565       1.8 $C_{15}H_{26}O$ 44       (Z,E)- $\alpha$ -Farnesene       1662.6       1491       0.2 $C_{15}H_{26}O$ 44       (Z,E)- $\alpha$ -Farnesene       1662.6       1491       0.2 $C_{15}H_{26}O$ 45       Caryophyllene oxide       1673.5       1589       0.9 $C_{15}H_{26}O$ 46       Succinic acid, di(1-(pentafluorophenyl)ethyl) ester       1699.4       1639       0.8 $C_{15}H_{26}O$ 48       13-Tetradecanoli	34	Thymol	1368.6	1294	0.3	C <sub>10</sub> H <sub>14</sub> O				
36       Geranyl acetate       1417.4       1383       0.3 $C_{11}H_{20}O_2$ 37       Jasmone       1468.6       1406       0.3 $C_{11}H_{16}O$ 38       Caryophyllene       1500.1       1423       0.2 $C_{13}H_{24}$ 39       Fragranyl 2-methylbutyrate       1511.9       1574.9       3.2 $C_{13}H_{26}O_2$ 40       Fragranyl isobutyrate       1557.4       1483.9       1.6 $C_{13}H_{26}O_2$ 41       Germacrene D       1564.9       1485       1.6 $C_{13}H_{26}O_2$ 42       Sesquicineole       1594.3       1515       0.8 $C_{15}H_{26}O$ 43       Nerolidol       1642.9       1565       1.8 $C_{15}H_{26}O$ 44       (Z,E)- $\alpha$ -Farnesene       1662.6       1491       0.2 $C_{13}H_{26}O$ 45       Caryophyllene oxide       1673.5       1589       0.9 $C_{13}H_{26}O$ 47 $\tau$ -Cadinol       1699.4       1639       0.8 $C_{15}H_{26}O$ 48       13-Tetradecanolide       1742.0       1643       0.4 $C_{14}H_{26}O_2$ 49       Levomenol=Kamillosan       1777.0       20	35	Myrtenyl acetate	1393.7	1335	0.6	C <sub>12</sub> H <sub>18</sub> O <sub>2</sub>				
37       Jasmone       1468.6       1406       0.3 $C_{11}H_{16}O$ 38       Caryophyllene       1500.1       1423       0.2 $C_{15}H_{24}$ 39       Fragranyl 2-methylbutyrate       1511.9       1574.9       3.2 $C_{15}H_{26}O_2$ 40       Fragranyl isobutyrate       1557.4       1483.9       1.6 $C_{14}H_{26}O_2$ 41       Germacrene D       1564.9       1485       1.6 $C_{15}H_{24}$ 42       Sesquicincole       1594.3       1515       0.8 $C_{15}H_{26}O$ 43       Nerolidol       1642.9       1565       1.8 $C_{15}H_{26}O$ 44       (Z,E)- $\alpha$ -Farnesene       1662.6       1491       0.2 $C_{15}H_{24}O$ 45       Caryophyllene oxide       1673.5       1589       0.9 $C_{15}H_{26}O$ 45       Succinic acid, di(1-(pentafluorophenyl)ethyl) ester       1699.4       1639       0.8 $C_{15}H_{26}O$ 48       13-Tetradecanolide       1774.0       1643       0.4 $C_{14}H_{26}O_2$ 49       Levomenol=Kamillosan       1777.0       2021       0.2 $C_{15}H_{20}O$ 50       Palmitoleic acid <td>36</td> <td>Geranyl acetate</td> <td>1417.4</td> <td>1383</td> <td>0.3</td> <td>C<sub>12</sub>H<sub>20</sub>O<sub>2</sub></td>	36	Geranyl acetate	1417.4	1383	0.3	C <sub>12</sub> H <sub>20</sub> O <sub>2</sub>				
38       Caryophyllene       1500.1       1423       0.2 $C_{15}H_{24}$ 39       Fragranyl 2-methylbutyrate       1511.9       1574.9       3.2 $C_{15}H_{26}O_2$ 40       Fragranyl isobutyrate       1557.4       1483.9       1.6 $C_{15}H_{26}O_2$ 41       Germacrene D       1564.9       1485       1.6 $C_{15}H_{26}O_2$ 42       Sesquicincole       1594.3       1515       0.8 $C_{15}H_{26}O_2$ 43       Nerolidol       1642.9       1565       1.8 $C_{15}H_{26}O_2$ 44       (Z,E)- $\alpha$ -Farnesene       1662.6       1491       0.2 $C_{15}H_{24}O_2$ 45       Caryophyllene oxide       1673.5       1589       0.9 $C_{15}H_{24}O_2$ 46       Succinic acid, di(1-(pentafluorophenyl)ethyl) ester       1699.4       1639       0.8 $C_{15}H_{26}O_2$ 47 $\tau$ -Cadinol       1699.4       1639       0.8 $C_{15}H_{26}O_2$ 48       13-Tetradecanolide       1777.0       2021       0.2 $C_{16}H_{30}O_2$ 50       Palmitoleic acid       1801.2       1953       0.2 $C_{16}H_{30}O_2$ 51       Dii	37	Jasmone	1468.6	1406	0.3	C <sub>11</sub> H <sub>16</sub> O				
39       Fragranyl 2-methylbutyrate       1511.9       1574.9       3.2 $C_{13}H_{26}O_2$ 40       Fragranyl isobutyrate       1557.4       1483.9       1.6 $C_{14}H_{26}O_2$ 41       Germacrene D       1564.9       1485       1.6 $C_{15}H_{26}O_2$ 42       Sesquicineole       1594.3       1515       0.8 $C_{15}H_{26}O_2$ 43       Nerolidol       1642.9       1565       1.8 $C_{15}H_{26}O_2$ 44       (Z,E)-a-Farnesene       1662.6       1491       0.2 $C_{15}H_{24}O_2$ 45       Caryophyllene oxide       1673.5       1589       0.9 $C_{15}H_{24}O_2$ 46       Succinic acid, di(1-(pentafluorophenyl)ethyl) ester       1699.4       2080       0.4 $C_{20}H_{12}F_{10}O_4$ 47 $\tau$ -Cadinol       1699.4       1639       0.8 $C_{15}H_{26}O_2$ 48       13-Tetradecanolide       1742.0       1643       0.4 $C_{14}H_{26}O_2$ 49       Levomenol=Kamillosan       1777.0       2021       0.2 $C_{16}H_{30}O_2$ 51       Diisobutyl phthalate = Phthalic acid, diisobutyl ester       1890.9       1868       0.2 $C_{16}H_{32}O_2$ <td>38</td> <td>Caryophyllene</td> <td>1500.1</td> <td>1423</td> <td>0.2</td> <td>C<sub>15</sub>H<sub>24</sub></td>	38	Caryophyllene	1500.1	1423	0.2	C <sub>15</sub> H <sub>24</sub>				
40Fragranyl isobutyrate157.41483.91.6 $C_{14}H_{26}O_2$ 41Germacrene D1564.914851.6 $C_{15}H_{24}$ 42Sesquicineole1594.315150.8 $C_{15}H_{26}O$ 43Nerolidol1642.915651.8 $C_{15}H_{26}O$ 44(Z,E)- $\alpha$ -Farnesene1662.614910.2 $C_{15}H_{24}O$ 45Caryophyllene oxide1673.515890.9 $C_{15}H_{24}O$ 46Succinic acid, di(1-(pentafluorophenyl)ethyl) ester1699.420800.4 $C_{20}H_{12}F_{10}O_4$ 47 $\tau$ -Cadinol1699.416390.8 $C_{15}H_{26}O$ 4813-Tetradecanolide1742.016430.4 $C_{14}H_{26}O_2$ 49Levomenol=Kamillosan1777.020210.2 $C_{15}H_{20}O$ 50Palmitoleic acid1801.219530.2 $C_{16}H_{30}O_2$ 51Diisobutyl phthalate = Phthalic acid, diisobutyl ester1890.918680.2 $C_{16}H_{30}O_2$ 52 $\alpha$ -Sinensal2062.517520.7 $C_{15}H_{26}O$ 53Palmitic acid2038.921406.3 $C_{18}H_{36}O_2$ 54Oleic acid2653.821881.1 $C_{18}H_{36}O_2$ 55Stearic acid2655.821881.1 $C_{18}H_{36}O_2$ 54Oleic acid2655.821881.1 $C_{18}H_{36}O_2$ 55Stearic acid2655.821881.1 $C_{18}H_{36}O_2$ <td>39</td> <td>Fragranyl 2-methylbutyrate</td> <td>1511.9</td> <td>1574.9</td> <td>3.2</td> <td>C<sub>15</sub>H<sub>26</sub>O<sub>2</sub></td>	39	Fragranyl 2-methylbutyrate	1511.9	1574.9	3.2	C <sub>15</sub> H <sub>26</sub> O <sub>2</sub>				
41       Germacrene D       1564.9       1485       1.6 $C_{15}H_{24}$ 42       Sesquicineole       1594.3       1515       0.8 $C_{15}H_{26}O$ 43       Nerolidol       1642.9       1565       1.8 $C_{15}H_{26}O$ 44       (Z,E)- $\alpha$ -Farnesene       1662.6       1491       0.2 $C_{15}H_{24}O$ 45       Caryophyllene oxide       1673.5       1589       0.9 $C_{15}H_{24}O$ 46       Succinic acid, di(1-(pentafluorophenyl)ethyl) ester       1699.4       2080       0.4 $C_{20}H_{12}F_{10}O_4$ 47 $\tau$ -Cadinol       1699.4       1639       0.8 $C_{15}H_{26}O$ 48       13-Tetradecanolide       1742.0       1643       0.4 $C_{14}H_{26}O_2$ 49       Levomenol=Kamillosan       1777.0       2021       0.2 $C_{16}H_{30}O_2$ 51       Diisobutyl phthalate =Phthalic acid, diisobutyl ester       1890.9       1868       0.2 $C_{16}H_{20}O_4$ 52       a-Sinensal       2062.5       1752       0.7 $C_{15}H_{26}O_2$ 53       Palmitic acid       2077.6       1964       2.3 $C_{16}H_{30}O_2$ 54	40	Fragranyl isobutyrate	1557.4	1483.9	1.6	C <sub>14</sub> H <sub>26</sub> O <sub>2</sub>				
42       Sesquicineole       1594.3       1515       0.8 $C_{15}H_{26}O$ 43       Nerolidol       1642.9       1565       1.8 $C_{15}H_{26}O$ 44       (Z,E)- $\alpha$ -Farnesene       1662.6       1491       0.2 $C_{15}H_{24}O$ 45       Caryophyllene oxide       1673.5       1589       0.9 $C_{15}H_{24}O$ 46       Succinic acid, di(1-(pentafluorophenyl)ethyl) ester       1699.4       2080       0.4 $C_{20}H_{12}F_{10}O_4$ 47       r-Cadinol       1699.4       1639       0.8 $C_{15}H_{26}O$ 48       13-Tetradecanolide       1742.0       1643       0.4 $C_{16}H_{26}O_2$ 49       Levomenol = Kamillosan       1777.0       2021       0.2 $C_{16}H_{30}O_2$ 50       Palmitoleic acid       1801.2       1953       0.2 $C_{16}H_{30}O_2$ 51       Diisobutyl phthalate = Phthalic acid, diisobutyl ester       1890.9       1868       0.2 $C_{16}H_{30}O_2$ 52       a-Sinensal       2062.5       1752       0.7 $C_{15}H_{22}O$ 53       Palmitic acid       2077.6       1964       2.3 $C_{16}H_{32}O_2$ 54<	41	Germacrene D	1564.9	1485	1.6	C <sub>15</sub> H <sub>24</sub>				
43       Nerolidol       1642.9       1565       1.8 $C_{15}H_{26}O$ 44       (Z,E)- $\alpha$ -Farnesene       1662.6       1491       0.2 $C_{15}H_{24}$ 45       Caryophyllene oxide       1673.5       1589       0.9 $C_{15}H_{24}O$ 46       Succinic acid, di(1-(pentafluorophenyl)ethyl) ester       1699.4       2080       0.4 $C_{20}H_{12}F_{10}O_4$ 47       r-Cadinol       1699.4       1639       0.8 $C_{15}H_{26}O$ 48       13-Tetradecanolide       1742.0       1643       0.4 $C_{14}H_{26}O_2$ 49       Levomenol = Kamillosan       1777.0       2021       0.2 $C_{15}H_{26}O$ 50       Palmitoleic acid       1801.2       1953       0.2 $C_{16}H_{30}O_2$ 51       Diisobutyl phthalate = Phthalic acid, diisobutyl ester       1890.9       1868       0.2 $C_{16}H_{32}O_4$ 52 $\alpha$ -Sinensal       2062.5       1752       0.7 $C_{15}H_{26}O$ 53       Palmitic acid       2638.9       2140       6.3 $C_{16}H_{32}O_2$ 54       Oleic acid       2655.8       2188       1.1 $C_{18}H_{36}O_2$ 55 <td>42</td> <td>Sesquicineole</td> <td>1594.3</td> <td>1515</td> <td>0.8</td> <td>C<sub>15</sub>H<sub>26</sub>O</td>	42	Sesquicineole	1594.3	1515	0.8	C <sub>15</sub> H <sub>26</sub> O				
44       (Z,E)- $\alpha$ -Farnesene       1662.6       1491       0.2 $C_{15}H_{24}$ 45       Caryophyllene oxide       1673.5       1589       0.9 $C_{15}H_{24}O$ 46       Succinic acid, di(1-(pentafluorophenyl)ethyl) ester       1699.4       2080       0.4 $C_{20}H_{12}F_{10}O_4$ 47       r-Cadinol       1699.4       1639       0.8 $C_{15}H_{26}O$ 48       13-Tetradecanolide       1742.0       1643       0.4 $C_{14}H_{26}O_2$ 49       Levomenol = Kamillosan       1777.0       2021       0.2 $C_{15}H_{26}O$ 50       Palmitoleic acid       1801.2       1953       0.2 $C_{16}H_{30}O_2$ 51       Diisobutyl phthalate = Phthalic acid, diisobutyl ester       1890.9       1868       0.2 $C_{16}H_{32}O_4$ 52 $\alpha$ -Sinensal       2062.5       1752       0.7 $C_{15}H_{26}O$ 53       Palmitic acid       2077.6       1964       2.3 $C_{16}H_{32}O_2$ 54       Oleic acid       2638.9       2140       6.3 $C_{18}H_{34}O_2$ 55       Stearic acid       2655.8       2188       1.1 $C_{18}H_{36}O_2$	43	Nerolidol	1642.9	1565	1.8	C <sub>15</sub> H <sub>26</sub> O				
45       Caryophyllene oxide       1673.5       1589       0.9 $C_{15}H_{24}O$ 46       Succinic acid, di(1-(pentafluorophenyl)ethyl) ester       1699.4       2080       0.4 $C_{20}H_{12}F_{10}O_4$ 47 $\tau$ -Cadinol       1699.4       1639       0.8 $C_{15}H_{26}O$ 48       13-Tetradecanolide       1742.0       1643       0.4 $C_{14}H_{26}O_2$ 49       Levomenol=Kamillosan       1777.0       2021       0.2 $C_{15}H_{26}O$ 50       Palmitoleic acid       1801.2       1953       0.2 $C_{16}H_{30}O_2$ 51       Diisobutyl phthalate = Phthalic acid, diisobutyl ester       1890.9       1868       0.2 $C_{16}H_{30}O_2$ 52 $\alpha$ -Sinensal       2062.5       1752       0.7 $C_{15}H_{22}O$ 53       Palmitic acid       2077.6       1964       2.3 $C_{16}H_{32}O_2$ 54       Oleic acid       2653.8       2188       1.1 $C_{18}H_{36}O_2$ 55       Stearic acid       2655.8       2188       1.1 $C_{18}H_{36}O_2$ 55       Stearic acid       2655.8       2188       1.1 $C_{18}H_{36}O_2$ 56 </td <td>44</td> <td>(Z,E)-α-Farnesene</td> <td>1662.6</td> <td>1491</td> <td>0.2</td> <td>C<sub>15</sub>H<sub>24</sub></td>	44	(Z,E)-α-Farnesene	1662.6	1491	0.2	C <sub>15</sub> H <sub>24</sub>				
46       Succinic acid, di(1-(pentafluorophenyl)ethyl) ester       1699.4       2080       0.4 $C_{20}H_{12}F_{10}O_4$ 47 $\tau$ -Cadinol       1699.4       1639       0.8 $C_{15}H_{26}O$ 48       13-Tetradecanolide       1742.0       1643       0.4 $C_{14}H_{26}O_2$ 49       Levomenol=Kamillosan       1777.0       2021       0.2 $C_{15}H_{26}O$ 50       Palmitoleic acid       1801.2       1953       0.2 $C_{16}H_{30}O_2$ 51       Diisobutyl phthalate = Phthalic acid, diisobutyl ester       1890.9       1868       0.2 $C_{16}H_{22}O_4$ 52 $\alpha$ -Sinensal       2062.5       1752       0.7 $C_{15}H_{22}O$ 53       Palmitic acid       2077.6       1964       2.3 $C_{16}H_{32}O_2$ 54       Oleic acid       2638.9       2140       6.3 $C_{18}H_{34}O_2$ 55       Stearic acid       2655.8       2188       1.1 $C_{18}H_{36}O_2$ 55       Stearic acid       2655.8       2188       1.1 $C_{18}H_{36}O_2$ 56       Stearic acid       2655.8       2188       1.1 $C_{18}H_{36}O_2$ 57	45	Caryophyllene oxide	1673.5	1589	0.9	C <sub>15</sub> H <sub>24</sub> O				
47       r-Cadinol       1699.4       1639       0.8 $C_{15}H_{26}O$ 48       13-Tetradecanolide       1742.0       1643       0.4 $C_{14}H_{26}O_2$ 49       Levomenol = Kamillosan       1777.0       2021       0.2 $C_{15}H_{26}O$ 50       Palmitoleic acid       1801.2       1953       0.2 $C_{16}H_{30}O_2$ 51       Diisobutyl phthalate = Phthalic acid, diisobutyl ester       1890.9       1868       0.2 $C_{16}H_{22}O_4$ 52       a-Sinensal       2062.5       1752       0.7 $C_{15}H_{26}O$ 53       Palmitic acid       2077.6       1964       2.3 $C_{16}H_{32}O_2$ 54       Oleic acid       2638.9       2140       6.3 $C_{18}H_{34}O_2$ 55       Stearic acid       2655.8       2188       1.1 $C_{18}H_{36}O_2$ 55       Stearic acid       2655.8       2188       1.1 $C_{18}H_{36}O_2$ 56       Total       99.5       99.5       1000000000000000000000000000000000000	46	Succinic acid, di(1-(pentafluorophenyl)ethyl) ester	1699.4	2080	0.4	C <sub>20</sub> H <sub>12</sub> F <sub>10</sub> O <sub>4</sub>				
48       13-Tetradecanolide       1742.0       1643       0.4 $C_{14}H_{26}O_2$ 49       Levomenol = Kamillosan       1777.0       2021       0.2 $C_{15}H_{26}O_2$ 50       Palmitoleic acid       1801.2       1953       0.2 $C_{16}H_{20}O_2$ 51       Diisobutyl phthalate = Phthalic acid, diisobutyl ester       1890.9       1868       0.2 $C_{16}H_{22}O_4$ 52 $\alpha$ -Sinensal       2062.5       1752       0.7 $C_{15}H_{22}O_4$ 53       Palmitic acid       2077.6       1964       2.3 $C_{16}H_{32}O_2$ 54       Oleic acid       2638.9       2140       6.3 $C_{18}H_{34}O_2$ 55       Stearic acid       2655.8       2188       1.1 $C_{18}H_{36}O_2$ 55       Stearic acid       2655.8       2188       1.1 $C_{18}H_{36}O_2$ 56       Total       99.5       99.5       99.5       99.5	47	τ-Cadinol	1699.4	1639	0.8	C <sub>15</sub> H <sub>26</sub> O				
49       Levomenol = Kamillosan       1777.0       2021       0.2 $C_{15}H_{26}O$ 50       Palmitoleic acid       1801.2       1953       0.2 $C_{16}H_{30}O_2$ 51       Diisobutyl phthalate = Phthalic acid, diisobutyl ester       1890.9       1868       0.2 $C_{16}H_{22}O_4$ 52 $\alpha$ -Sinensal       2062.5       1752       0.7 $C_{15}H_{22}O$ 53       Palmitic acid       2077.6       1964       2.3 $C_{16}H_{32}O_2$ 54       Oleic acid       2638.9       2140       6.3 $C_{18}H_{34}O_2$ 55       Stearic acid       2655.8       2188       1.1 $C_{18}H_{36}O_2$ 55       Stearic acid       2655.8       2188       1.1 $C_{18}H_{36}O_2$ 56       Total       99.5       99.5       1000000000000000000000000000000000000	48	13-Tetradecanolide	1742.0	1643	0.4	C <sub>14</sub> H <sub>26</sub> O <sub>2</sub>				
50       Palmitoleic acid       1801.2       1953       0.2 $C_{16}H_{30}O_2$ 51       Diisobutyl phthalate = Phthalic acid, diisobutyl ester       1890.9       1868       0.2 $C_{16}H_{22}O_4$ 52 $\alpha$ -Sinensal       2062.5       1752       0.7 $C_{15}H_{22}O$ 53       Palmitic acid       2077.6       1964       2.3 $C_{16}H_{32}O_2$ 54       Oleic acid       2638.9       2140       6.3 $C_{18}H_{34}O_2$ 55       Stearic acid       2655.8       2188       1.1 $C_{18}H_{36}O_2$ Total       99.5       99.5       1000000000000000000000000000000000000	49	Levomenol = Kamillosan	1777.0	2021	0.2	C <sub>15</sub> H <sub>26</sub> O				
51       Diisobutyl phthalate = Phthalic acid, diisobutyl ester       1890.9       1868       0.2 $C_{16}H_{22}O_4$ 52 $\alpha$ -Sinensal       2062.5       1752       0.7 $C_{15}H_{22}O_4$ 53       Palmitic acid       2077.6       1964       2.3 $C_{16}H_{32}O_2$ 54       Oleic acid       2638.9       2140       6.3 $C_{18}H_{34}O_2$ 55       Stearic acid       2655.8       2188       1.1 $C_{18}H_{36}O_2$ Total         Continued	50	Palmitoleic acid	1801.2	1953	0.2	C <sub>16</sub> H <sub>30</sub> O <sub>2</sub>				
52 $\alpha$ -Sinensal       2062.5       1752       0.7 $C_{15}H_{22}O$ 53       Palmitic acid       2077.6       1964       2.3 $C_{16}H_{32}O_2$ 54       Oleic acid       2638.9       2140       6.3 $C_{18}H_{34}O_2$ 55       Stearic acid       2655.8       2188       1.1 $C_{18}H_{36}O_2$ Total       99.5       99.5       99.5	51	Diisobutyl phthalate = Phthalic acid, diisobutyl ester	1890.9	1868	0.2	C <sub>16</sub> H <sub>22</sub> O <sub>4</sub>				
53       Palmitic acid       2077.6       1964       2.3       C <sub>16</sub> H <sub>32</sub> O <sub>2</sub> 54       Oleic acid       2638.9       2140       6.3       C <sub>18</sub> H <sub>34</sub> O <sub>2</sub> 55       Stearic acid       2655.8       2188       1.1       C <sub>18</sub> H <sub>36</sub> O <sub>2</sub> Total       99.5       99.5	52	α-Sinensal	2062.5	1752	0.7	C <sub>15</sub> H <sub>22</sub> O				
54         Oleic acid         2638.9         2140         6.3         C <sub>18</sub> H <sub>34</sub> O <sub>2</sub> 55         Stearic acid         2655.8         2188         1.1         C <sub>18</sub> H <sub>36</sub> O <sub>2</sub> Total         99.5         99.5         99.5	53	Palmitic acid	2077.6	1964	2.3	C <sub>16</sub> H <sub>32</sub> O,				
55         Stearic acid         2655.8         2188         1.1         C <sub>18</sub> H <sub>36</sub> O <sub>2</sub> Total         99.5         99.5         99.5	54	Oleic acid	2638.9	2140	6.3	C <sub>18</sub> H <sub>34</sub> O,				
Total     99.5	55	Stearic acid	2655.8	2188	1.1	C <sub>18</sub> H <sub>36</sub> O,				
Continued		Total			99.5	10 50 2				
	Con									

No	Compound	RI Exp	RI Lit	Concentration (%)	Molecular formula
	Monoterpenes hydrocarbons			6.5	
	Oxygenated monoterpenes			47.8	
	Sesquiterpenes hydrocarbons			2	
	Oxygenated sesquiterpenes			4.5	
	Others (Nonterpenoids)			38.7	

**Table 1.** Chemical name, retention time, concentration and structure formula of compounds found in theessential oil obtained from A. wilhelmsii. Compounds are listed in order of their retention time from an HP-5column. RI  $_{Exp}$ , linear retention indices on HP-5 column, experimentally determined using homolog series ofn-alkanes (C8-C20). RI  $_{Lit}$ , Linear retention index taken from Adams (2007), or NIST 14 (2014) and literature.





These findings are consistent with some studies but vary in concentration depending on the growth habitat. Notably,  $\alpha$ -pinene is known for its antimicrobial properties<sup>51,52</sup>. Linalool, a monoterpene alcohol, has diverse pharmacological effects, including antioxidant, anti-inflammatory, and antimicrobial properties<sup>53</sup>. Camphor, widely used for its medicinal properties, exhibits antiseptic and antitussive effects and modulates various physiological functions<sup>54</sup>. Minor components detected in the essential oil included fragranyl 2-methylbutyrate (3.17%), palmitic acid (2.32%), and 1,8-Cineole (2.16%). Fragranyl 2-methylbutyrate was identified for the first time in *A. wilhelmsii* essential oil, while palmitic acid and 1,8-Cineole were detected in trace amounts in previous studies. The beneficial properties of 1,8-Cineole include anti-inflammatory and antioxidant activities<sup>55</sup>. Overall, these results highlight the significant impact of growth habitat on the composition and beneficial properties of *A. wilhelmsii* essential oil. The unique chemotype identified in the *A. wilhelmsii* cultivated in the Maragheg area of the Kashan region suggests its potential as a distinct and valuable resource in natural product research<sup>56,57</sup>.

#### Antimicrobial activity of essential oil

The antimicrobial activity of the essential oil extracted from A. wilhelmsii against selected microorganisms was evaluated, resulting in varying inhibition halos (Table 2; Fig. 2). Notably, the largest inhibition halo (~10 mm) was observed against Candida albicans, though lower compared to nystatin (~33 mm) and consistent with previous findings<sup>33</sup>. Candida albicans, a common fungal pathogen, can lead to severe infections, particularly in immunocompromised individuals, highlighting the significance of effective antifungal agents<sup>58,59</sup>. The efficacy of the essential oil against C. albicans and other microorganisms can be attributed to its composition, which is influenced by the plant's growth habitat<sup>60,61</sup>. The inhibition halo against Gram-positive Staphylococcus aureus (~10 mm) was lower compared to rifampin (~21 mm) and gentamicin (~27 mm), indicating moderate antibacterial activity. Similarly, previous studies reported varying inhibition halos for A. wilhelmsii essential oil against S. aureus<sup>31,33</sup>. Staphylococcus aureus is a dangerous strain mainly responsible of hospital-acquired infections, necessitating effective antimicrobial agents<sup>62</sup>. Additionally, the essential oil exhibited inhibition against Bacillus subtilis (~9.5 mm), an opportunistic pathogen associated with eye infections and septicemia. This inhibitory effect, not previously reported by others, suggests the potential of A. wilhelmsii essential oil as an antibacterial agent<sup>49,63</sup>. Surprisingly, strong inhibitory activity was observed against Gram-negative Acinetobacter baumannii (~9 mm) and Shigella dysenteriae (~9 mm), outperforming rifampin. A. baumannii and Sh. dysenteriae are causative agents of various infections, highlighting the significance of effective treatments<sup>64,65</sup>. The novel inhibitory effect against these Gram-negative bacteria suggests the potential of A. wilhelmsii essential oil as a natural antibacterial agent. The minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) of the essential oil were measured, ranging from 1000 to 8000 µg/mL and consistent with previous studies<sup>66</sup>. While the MIC values were relatively high compared to control antibiotics, further investigation is warranted to elucidate the mechanism of action and optimize the antimicrobial efficacy of the essential oil<sup>67</sup>. Overall, the antimicrobial activity of A. wilhelmsii essential oil against a range of pathogenic microorganisms underscores its potential as a natural antimicrobial agent. Further research into its mode of action and formulation for clinical use is warranted to harness its therapeutic benefits effectively.

#### Conclusion

In this study, we successfully extracted a bluish-green essential oil from A. wilhelmsii cultivated in the natural habitat of Kashan, marking the first instance of such extraction. Our findings revealed a nearly unique qualitative composition of the essential oil, characterized by a predominance of oxygenated sesquiterpene

	A. wilhelmsii essential oil		Rifampin		Gentamicin		Nystatin			
Standard strains	IH (mm)	MIC (µg/mL)	MBC (µg/mL)	IH (mm)	MIC (µg/mL)	IH (mm)	MIC (µg/mL)	IH (mm)	MIC (µg/mL)	
Gram-positive bacteria										
B. subtilis	$9.50 \pm 1.50^{\circ}$	1000	2000	$19.00\pm0.00^{\rm b}$	31.25	$30.00 \pm 0.00^{a}$	3.90	NA	NA	
S. aureus	$10.00 \pm 0.00^{\circ}$	2000	2000	$21.00\pm0.00^a$	31.25	$27.00 \pm 0.00^{b}$	1.95	NA	NA	
S. epidermidis	ND	2000	2000	$27.00\pm0.00^{\rm b}$	1.95	$45.00 \pm 0.00^{a}$	1.95	NA	NA	
Gram-negative bacteria										
E. coli	ND	8000	8000	$11.00\pm0.00^{\rm b}$	3.90	$20.00 \pm 0.00^{a}$	3.90	NA	NA	
K. pneumoniae	ND	4000	8000	$8.00\pm0.00^{\rm b}$	15.63	$17.00 \pm 0.00^{a}$	3.90	NA	NA	
P. aeruginosa	ND	1000	2000	ND	31.25	$20.00 \pm 0.00^{a}$	7.81	NA	NA	
S. paratyphi-A	ND	1000	2000	$8.00\pm0.00^{\rm b}$	15.63	$18.00 \pm 0.00^{a}$	3.90	NA	NA	
Sh. dysenteriae	$9.00 \pm 0.00^{b}$	2000	4000	$9.00\pm0.00^{\rm b}$	15.63	$17.00 \pm 0.00^{a}$	3.90	NA	NA	
A. baumannii	$9.00 \pm 0.00^{b}$	2000	2000	$8.00 \pm 0.00^{\circ}$	7.81	$17.00 \pm 0.00^{a}$	3.90	NA	NA	
P. mirabilis	ND	2000	2000	$9.00\pm0.00^{\rm b}$	15.63	$20.00 \pm 0.00^{a}$	31.25	NA	NA	
Yeast strain										
C. albicans	$10.00\pm0.00^{\rm b}$	4000	4000	NA	NA	NA	NA	$33.00 \pm 0.00^{a}$	125	

**Table 2.** Inhibition halos (IH), minimum inhibitory concentration (MIC) and minimum bactericidal concentration of essential oil obtained from *A. wilhelmsii* or rifampicin or gentamicin or nystatin used as positive controls. Mean values  $\pm$  standard deviations are reported. Values with different letters are statistically different (Duncan,  $p \le 0.01$ ).



Fig. 2. Inhibition halos of essential oil obtained from A. wilhelmsii against selected microorganisms.

compounds, particularly fragranol, along with acidic compounds like fragranyl acetate, oleic acid, and fragranyl 2-methylbutyrate. This underscores the significant influence of the plant's growth habitat and environmental conditions on the synthesis of different chemical compounds. Moreover, the distinctive composition of the essential oil was associated with significant inhibition halos against some pathogenic microorganisms, notably the Gram-negative bacteria *A. baumannii* and *Sh. dysenteriae*. These findings highlight the potential of *A. wilhelmsii* essential oil as a natural antimicrobial agent, particularly against challenging Gram-negative pathogens. Given the ethnobotanical significance of *A. wilhelmsii* in Iran, particularly in Kashan city, its essential oil holds promise as a natural option for the treatment of various microbial infections. However, further studies are warranted to validate its beneficial properties and explore its potential therapeutic applications in clinical settings.

#### Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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#### References

- 1. Petrakoua, K., Iatroub, G. & Lamari, F. N. Ethnopharmacological survey of medicinal plants traded in herbal markets in the Peloponnisos, Greece. J. Herb. Med. 19, 100305 (2020).
- 2. Farooq, A. et al. Ethnomedicinal knowledge of the rural communities of Dhirkot, Azad Jammu and Kashmir, Pakistan. J. Ethnobiol. Ethnomed. 15, 45 (2019).
- 3. Malik, K. et al. An ethnobotanical study of medicinal plants used to treat skin diseases in northern Pakistan. *BMC Complement. Altern. Med.* **19**, 210 (2019).
- 4. Zizka, A. et al. Traditional plant use in Burkina Faso (West Africa): A national-scale analysis with focus on traditional medicine. *J. Ethnobiol. Ethnomed.* **11**, 9 (2015).
- 5. Aziz, Z. A. A. et al. Essential oils: Extraction techniqes, pharmaceutical and therapeutic potential—A review. *Curr. Drug Metab.* **19**, 1100–1110 (2018).

- 6. Božović, M., Mladenović, M. & Ragno, R. Editorial: Chemical composition-and antimicrobial activity of essential oils. *Front. Pharmacol.* **14**, 1120756 (2023).
- Kürekci, C. & Sakin, F. Uçucu Yağlar: Antimikrobiyal açıdan uçucu yağlar: In-vitro ve in-vivo çalışmalar. Türk. Klini. Hayvan Besleme Beslenme Hastalık. Derg. Özel Konular 3, 15–20 (2017).
- 8. Ghavam, M. Antibacterial potential of biosynthesized silver nanoparticles using *Nepeta sessilifolia* Bunge and *Salvia hydrangea* DC. ex Benth. extracts from the natural habitats of Iran's Rangelands. *BMC Complement. Med. Ther.* 23, 299 (2023).
- 9. Şahan, Z. Bazı Bitki Uçucu Yağlarının Enerji, Protein ve Lif Kaynağı Yemlerin In Vitro Gerçek Sindirilebilirliğine ve Yüksek Verimli süt Sığırlarında süt Verimi ve süt Kompozisyonlarına Etkileri 1–147 (Çukurova Üniversitesi Fen Bilimleri Enstitüsü, 2012).
- Kurkiazizi, M., Chizzola, R., Ghani, A. & Oroojalian, F. Composition at different development stages of the essential oil of four Achillea species grown in Iran. Nat. Prod. Commun. 5(2), 283–290 (2010).
- Taheri Boukani, K. & Najafzadeh, R. Evaluation of diversity of yarrow (*Achillea biebersteinii* Afan. and *Achillea wilhelmsii* C. Koch) populations in West-Azerbaijan province based on morphological traits, essential oil percentage and composition. *Iran. J. Hortic. Sci.* 51, 215–228 (2019).
- 12. Vaez Shahrestani, A. & Sefidkon, F. Essential oil composition in different plant parts of *Achillea biebersteinii* Afam. *Med. Aromat. Plan* **34**, 40–49 (2018).
- Achakzai, J. K. et al. In vitro antileishmanial activity and GC–MS analysis of whole plant hexane fraction of Achillea wilhelmsii (WHFAW). J. Microorg.Linalool. Mol. 27, 6928 (2022).
- 14. Mozaffarian, V. A Dictionary of Iranian plant names 596 (Farhang Moaser Publication, 1996).
- 15. Aytac, Z., Duman, H. & Ekici, M. Two new Achillea L. (Asteraceae) species from Turkey. Turk. J. Bot. 40, 373-379 (2016).
- 16. Saeidnia, S., Gohari, A., Mokhber-Dezfuli, N. & Kiuchi, F. A. A review on phytochemistry and medicinal properties of the genus Achillea. DARU J. Fac. Pharm. Tehran Univ. Med. Sci. 19, 173 (2011).
- 17. Applequist, W. L. & Moerman, D. E. Yarrow (Achillea millefolium L.): A neglected panacea? A review of ethnobotany, bioactivity, and biomedical research. Econ. Bot. 65, 209–225 (2011).
- 18. Zargari, A. Medicinal Plants Vol. 3, 107-117 (Tehran University Publications, 1996).
- 19. Salehi, M., Kalvandi, R. & Salehi, F. Evaluation of morphological traits and essential oil constituents diversity in different populations of *Achillea santolinoides* subsp. *wilhelmsii* (K. Koch) Greuter in Hamedan Province. *J. Hortic. Sci.* In Press (2023).
- Mohammadhosseini, M., Sarker, S. D. & Akbarzadeh, A. Chemical composition of the essential oils and extracts of *Achillea* species and their biological activities: A review. J. Ethnopharmacol. 199, 257–315 (2017).
- 21. Fekri Qomi, S., Sefidkon, F. & Salehi Shanjani, P. Study of morphological characteristics and essential oil of different populations of *Achillea wilhelmsii* C. Koch. *Iran. J. Med. Aromat. Plants Res.* 34, 579–593 (2018).
- 22. Ali, N. et al. Acute toxicity and antispasmodic activities of Achillea wilhelmsii C. Koch. Pak. J. Pharm. Sci. 27, 309-315 (2014).
- 23. Ghavam, M. & Kiani, S. Ethnobutanical analysis of medicinal plants in Kashan. Nat. Ecosyst. Iran 9, 103-125 (2018).
- Delfan, E. D. & Azizi, K. Ethnobotany of native medicinal plants in Zagheh and Biranshahr districts, Lorestan Province, Iran. Ecophytochem. J. Med. Plants 7, 64–82 (2020).
- 25. Bazgir, A. & Mehdi, P. Ethnobotany of wild plants in Bestam region of Selseleh county, Lorestan Province. *Indig. Knowl.* 8, 85–158 (2021).
- Koushki, M., Farrokhi Yekta, R., Amiri-Dashatan, N., Dadpay, M. & Goshadrou, F. Therapeutic effects of hydro-alcoholic extract of *Achillea wilhelmsii* C. Koch on indomethacin-induced gastric ulcer in rats: a proteomic and metabolomic approach. *BMC Complement. Altern. Med.* 19, 2623 (2019).
- 27. Asgary, S. et al. Antihypertensive and antihyperlipidemiceffects of Achillea wilhelmsii. Drugs Exp. Clin. Res. 26, 89-93 (2000).
- Ashtiani, M. et al. Effect of Achillea wilhelmsii extract on expression of the human telomerase reverse transcriptase mRNA in the PC3 prostate cancer cell line. Biomed. Rep. 7, 251–256 (2017).
- 29. Majnooni, M. B., Mohammadi-Farani, A., Gholivand, M. B., Nikbakht, M. R. & Bahrami, G. R. Chemical composition and anxiolytic evaluation of *Achillea wilhelmsii* C. Koch essential oil in rat. *Res. Pharm. Sci.* **8**, 269–275 (2013).
- 30. Raudone, L. et al. Distribution of phenolic compounds and antioxidant activity in plant parts and populations of seven under utilized wild Achillea species. *Plants* 11, 447 (2022).
- Akbar, A., Gul, Z., Chein, S. H. & Sadiq, M. B. Investigation of anti-inflammatory properties, phytochemical constituents, antioxidant, and antimicrobial potentials of the whole plant ethanolic extract of *Achillea santolinoides* subsp. wilhelmsii (K. Koch) Greuter of Balochistan. Oxid. Med. Cell. Longev. (2023).
- 32. Chalabian, F., Norouzi Arasi, H. & Moosavi, S. A study of growth inhibitory effect of essential oils of seven species from different families on some kinds of microbes. J. Med. Plants 2, 37-42 (2003). Chemistry 2019, 5734257, 26, (2019).
- Azaz, A. D., Arabaci, T., Sangun, M. K. & Yildiz, B. Composition and the in vitro antimicrobial activities of the essential oils of Achillea wilhelmsii C. Koch and Achillea lycaonica Boiss & Heldr. Asian J. Chem. 20, 1238–1244 (2008).
- 34. Ghadri, S., Falahati Hossein Abad, A., Sarailo, M. & Ghanbari, V. Investigating the compounds and antibacterial effect of three essential oils of coriander, yarrow and dill in laboratory conditions. J. Shahrekord Univ. Med. Sci. 14, 74–82 (2012).
- Nejadhabibvash, F. & Rezaee, M. Variation in the essential oil of Achillea wilhelmsii C. Koch and A. millefolium L. apical shoots in different developmental stages in Martyrs Valley, West Azerbaijan province: A Case example. Iran. J. Plant Biol. 10, 17–38 (2018).
- Rabbi Angourani, H. Investigation of phytochemical compounds of Achillea wilhelmsii C. Koch essential oil in Zanjan province natural habitats. J. Med. Plants Biotechnol. 5, 57–63 (2020).
- Azarnivand, H., Ghavam Arabani, M., Sefidkon, F. & Tavili, A. The effect of ecological characteristics on quality and quantity of the essential oils of *Achillea millefolium* L. subsp. Millefolium. *Iran. J. Med. Aromat. Plants Res.* 25, 556–571 (2010).
- Adams, R. P. Identification of Essential Oil Components by Gas Chromatography/Quadruple Mass Spectroscopy. Carol Stream IL, 804 (Allured Publishing Cropration, 2007).
- CLSI. Clinical and Laboratory Standard Institute. Performance Standards for Antimicrobial Disk Susceptibility Testing: Approved Standard, vol. 29, 1–76 (National Committee for Clinical Laboratory Standards, 2012).
- Azadbakht, M., Morteza-Semnani, K. & Khansari, N. The essential oils composition of Achillea wilhelmsii C. Koch leaves and flowers. J. Med. Plants 2, 55–58 (2003).
- Angourani, H. R., Zarei, A., Moghadam, M. M., Ramazani, A. & Mastinu, A. Investigation on the essential oils of the Achillea species: From chemical analysis to the in silico uptake against SARS-CoV-2 main protease. *Life* 13, 378 (2023).
- 42. Nejadhabibvash, F. et al. Study of the plant growth stages effect on the color, content and composition of essential oil of *Achillea* wilhelmsii C. Koch Case Study: Qushchi Ghat in West Azerbaijan province. *Eco-phytochem. J. Med. Plants* **5**, 47–64 (2017).
- Ghavam, M., Azarnivand, H., Sefidkon, F. & Tavili, A. Comparison of the quantity and quality of the essential oils of the flowers and leaves of the two subspecies of *Achillea millefolium* L. with the pharmacy source approach. *AUMJ* 9, 345–356 (2020).
- 44. Ghavam, M., Azarnivand, H., Sefidkon, F. & Tavili, A. Comparison of the quantity and quality of the essential oils of the flowers and leaves of the two subspecies of *Achillea millefolium* L. with the pharmacy source approach. *Alborz Univ. Med. J.* **9**, 345–356 (2020).
- Najafzadeh, R., Aliyi, A. & Taheri Boukani, K. Comparing the essential oils percentage and compositions in different organs of Achillea wilhelmsii C. Koch. Technol. Med. Aromat. Plants Iran 5, 14–21 (2023).
- Turkmenoglu, F. P., Agar, O. T., Akaydin, G., Hayran, M. & Demirci, B. Characterization of volatile compounds of eleven Achillea species from Turkey and biological activities of essential oil and methanol extract of A. hamzaoglui Arabaci et Budak. Molecules 20, 11432–11458 (2015).

- Bader, A. et al. Essential oil biodiversity of Achillea ligustica All. Obtained from Mainland and Island populations. Plants 11, 1054 (2022).
- Bohlmann, F., Zdero, C. & Faass, U. Naturally occurring terpene derivatives. XXVI. Constituents of Artemisia fragrans. Chem. Ber. 106, 2904–2909 (1973).
- 49. Dilika, F., Bremner, P. D. & Meyer, J. J. Antibacterial activity of linoleic and oleic acids isolated from *Helichrysum pedunculatum*: A plant used during circumcision rites. *Fitoterapia* 71, 450–452 (2000).
- Mirbagheri Firoozabad, M. S. & Mohammadi, N. M. Antimicrobial activities of microbial essential fatty acid against foodborne pathogenic bacteria. *Iran. J. Microbiol.* 14, 214–218 (2022).
- Borges, M. F. D. A., Lacerda, R. D. S., Correia, J. P. D. A., de Melo, T. R. & Ferreira, S. B. Potential antibacterial action of α-pinene. Med. Sci. Forum 12, 1–11 (2022).
- 52. Silva, A. C. R. et al. Biological activities of a-pinene and  $\beta$ -pinene enantiomers. *Molecules* 17, 6305–6316 (2012).
- 53. Maczka, W. et al. A new approach to functionalized cyclobutanes: Stereoselective synthesis of the enantiomers of grandisol and fraganol. *Tetrahedron Asymmetry* **6**, 1151–1164 (1995).
- Sikka, S. C. & Bartolome, A. R. Perfumery, essential oils, and household chemicals affecting reproductive and sexual health. In Bioenvironmental Issues Affecting Men's Reproductive and Sexual Health, 557–569 (Academic Press, 2018).
- 55. Cai, Z. M. et al. 1, 8-Cineole: A review of source, biological activities, and application. J. Asian Nat. Prod. Res. 23, 938-954 (2021).
- 56. Ghavam, M. A GC–MC analysis of chemical compounds and identification of the antibacterial characteristics of the essential oil of two species exclusive to Iranian habitats: New chemotypes. *PLoS ONE* **17**, e0273987 (2022).
- Ghavam, M. & Markabi, F. S. Evaluation of yield, chemical profile, and antimicrobial activity of *Teucrium polium* L. essential oil used in Iranian folk medicine. *Appl. Biochem. Biotechnol.* https://doi.org/10.1007/s12010-023-04847-6 (2024).
- Janbon, G., Quintin, J., Lanternier, F. & d'Enfert, C. Studying fungal pathogens of humans and fungal infections: Fungal diversity and diversity of approaches. *Genes Immun.* 20, 403–414 (2019).
- Xiao, Z., Wang, Q., Zhu, F. & An, Y. Epidemiology, species distribution, antifungal susceptibility and mortality risk factors of candidemia among critically ill patients: A retrospective study from 2011 to 2017 in a teaching hospital in China. Antimicrob. Resist. Infect. Control 8, 89 (2019).
- 60. Ghavam, M. In vitro biological potential of the essential oil of some aromatic species used in Iranian traditional medicine. *Inflammopharmacology* **30**, 855–874 (2022).
- Oroojalian, F., Kasra-Kermanshahi, R., Azizi, M. & Bassami, M. Synergistic antibacterial activity of the essential oils from three medicinal plants against some important food-borne pathogens by microdilution method. *Iran. J. Med. Aromat. Plants Res.* 26, 133–146 (2010).
- 62. Khaleghi, M., Bokaiean, M. & Saeedi, S. Assessment of antimicrobial activity of Myrtus communis extract against methicillinresistant *Staphylococcus aureus*. Appl. Biol. 26, 37–46 (2014).
- Gilsic, S., Milojeij, S., Dimitrjvi, J., Orlovij, A. & Skala, D. Antimicrobial activity of the essential oil and different fractions of Juniperus communis L. and a comparison with some commercial antibiotics. J. Serb. Chem. Soc. 72, 311–320 (2007).
- 64. Babapour, E., Haddadi, A., Mirnejad, R., Angaji, S. & Amirmozafari, N. Study of drug resistance and ompA gene existence in clinical *Acinetobacter baumannii* isolates. *Iran. J. Med. Microbiol.* **11**, 30–38 (2017).
- 65. Arianzad, S. A., Zeinoddini, M., Haddadi, A., Nazarian, S. & Hasan Sajedi, R. The effect of recombinant IpaB protein on the development of immune responses against *Shigella dysenteriae* in Guinea Pig. J. Microb. World 15, 170–182 (2022).
- 66. Ghaderi, S., Falahati Hosein Abad, A., Sarailoo, M. H. & Ghanbari, V. Investigation of the components and antibacterial effects of three plant's essential oil *Coriandrum sativum*, *Achilleh millefolium*, *Anethum graveolens* in vitro. *J. Shahrekord Univ. Med. Sci.* 14, 74–82 (2012).
- Holly, R. A. & Patal, D. Improvement in shelf life and safetey of perishable foods by plant essential oils and smoke antimicrobials. Food Chem. 22, 273–292 (2005).

#### Author contributions

M.G. was the supervisor, designer of the hypotheses, and responsible for all the steps (laboratory, statisticalanalysis, data analysis, etc.) and wrote the text of the article. G.B. identified and confirmed the study plants, wrote part of the text and did the revision and formatting of the work. I.C., M.M. and M.L.M. wrote the text and did the revision and formatting of the work. Also M.L.M. interpretated part of data, substantively revised the text and edited English language.

#### Declarations

#### **Competing interests**

The authors declare no competing interests.

#### Ethical approval and consent to participate

All methods conducted comply with relevant institutional, national, and international guidelines and legislation.

#### Additional information

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