Chemical Composition and Antimicrobial Activity of the Essential Oils from Three Chemotypes of Origanum vulgare L. ssp. hirtum (Link) Ietswaart Growing Wild in Campania (Southern Italy)

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Abstract: Essential oils obtained from inflorescences of three Origanum vulgare L. ssp. hirtum (Link) Ietswaart samples, growing wild in different locations in Campania (Southern Italy), were analysed. Three chemotypes were found: the first, with a prevalence of carvacrol/thymol; the second, characterized by the prevalence of thymol/α-terpineol; the third, featuring a prevalence of linalyl acetate and linalool. This chemical study attempts to provide a contribution in shedding light on the relationship between chemical composition and biotypes and/or chemotypes in Origanum vulgare ssp. hirtum. The essential oils were also evaluated for their antibacterial activity against 10 selected microorganisms. The data obtained contribute to the future view to use the essential oils as natural preservatives for food products, due to their positive effect on their safety and shelf life.

Keywords: Origanum vulgare ssp. hirtum; essential oil composition; thymol; carvacrol; linalyl acetate; antibacterial activity
**Introduction**

Many different species, commonly known as oregano or origanum, are of economic interest, although they belong to different botanical families and genera. Four main groups commonly used for culinary purposes can be distinguished, i.e., Greek oregano (Origanum vulgare L. ssp. hirtum (Link) Ietswaart), Spanish oregano (Coridothymus capitatus (L.) Hoffmanns & Link), Turkish oregano (Origanum onites L.) and Mexican oregano (Lippia graveolens HBK) [1-3]. In Europe and, in general, all over the world, the most commonly found oregano species belong to the botanical genus Origanum. Within this genus, Ietswaart [4], based on morphological criteria, recognised three groups, 10 sections, 38 species, six subspecies and 17 hybrids. Before 1980, O. vulgare L. referred indifferently the subspecies that Ietswaart later identified as O. vulgare L. ssp. hirtum (Link) Ietswaart, O. vulgare L. ssp. gracile (C. Koch) Ietswaart, O. vulgare L. ssp. vulgare, and O. vulgare L. ssp. viride (Boiss.) Hayek. The O. vulgare subspecies are not easily distinguishable by their morphological aspects alone. It is not surprising that many analytical investigations about oregano essential oils did not discriminate between the numerous subspecies that show subtle morphological and chemical differences. The characteristics which seem to be quite constant are the yield and the composition of their essential oils, thus being these characteristics useful for subspecies identification. O. vulgare L. ssp. vulgare and O. vulgare ssp. hirtum (Link) Ietswaart are commercial species. A few references have reported on the first species [5-8], while more numerous works have dealt with the second [8-14], even if the reported data can vary widely depending on the different growing conditions and geographical areas in which the analyzed plants were collected [2]. Origanum vulgare L. ssp. hirtum (Link) Ietswaart is a typical East Mediterranean taxon. Ecologically, this species prefers warm, sunny habitats and loose, often rocky, calcareous soils, usually low in moisture content. Though very variable in morphological aspects, it can be distinguished from other O. vulgare subspecies by its hairy stems, compact inflorescences, leaves and calyces densely covered with glandular structures, green bracts, which are usually as long as calyces, and white flowers [15]. A number of studies have shown that O. vulgare ssp. hirtum is a very variable taxon both in morphological and in chemical features [16], with an essential oil whose principal components are phenols, p-cymene, and γ-terpinene [2]. As a continuation of our research on the oils of the Lamiaceae growing wild in Southern Italy [17-22], in this work we examined the composition of the essential oils of three O. vulgare L. ssp. hirtum populations growing wild in Campania (Southern Italy) and their antimicrobial activity on ten selected microorganism. O. vulgare ssp. hirtum is largely employed as an aromatizer in both traditional and modern foods, namely in Southern part of Italy. Its use is very old and this plant is often collected from wild populations, dried and then preserved in kitchen cupboards.

**Results and Discussion**

*Chemical composition of the essential oils*

The isolated oils were dried over anhydrous sodium sulphate and stored at 4-6 °C under N₂. The dry materials gave yellow-reddish oils in a yield 2.35% (w/w, F), 3.15% (w/w, S), and 2.93% (w/w, SG) of essential oil, characterized by a typical odour.
Table 1 shows the relative percentage of the volatile components identified in the oils; compounds are listed according to their linear retention indices (LRIs) on a HP 5MS column. A total of 64 compounds have been identified in the three oils. The essential oil composition of the three populations of plants appeared quite different and allows us to identify three different chemotypes. In fact, the first and second oil were characterized by high percentages of phenols, but while the Furore oil (F) can be classified as a carvacrol/thymol chemotype, the Sanza sample (S) can be classified as a thymol/α-terpineol chemotype. The oil from San Giovanni a Piro (SG) could be classified as a linalyl acetate/linalool chemotype, with these compounds accounting for 15.90% and 12.50%, respectively. In F, the total phenol content represents 45.70% of the oil with comparable percentages of carvacrol, thymol and their derivatives (23.34% and 22.16%, respectively). In S, total phenols represent 40.50% of the oil with a prevalence of thymol and its derivatives (29.33%) while in SG the phenolic fraction accounted to 6.30% of the oil, the half of which is represented by thymol (3.24%). Monoterpene hydrocarbons were present in different amounts: 11.60%, 15.60% and 26.30%, respectively for the F, S and SG oil, but in all cases γ-terpinene and p-cymene were the most abundant. γ-Terpinene and p-cymene, the biosynthetic precursors of monoterpenoid phenols, were present in the same amount in the oil F (2.38% and 2.81%, respectively), while in the oil S γ-terpinene (4.59%) was detected in a higher percentage than in the oil F, but it wasn’t the same for p-cymene (1.25%). However, in both cases, the two monoterpene hydrocarbons, γ-terpinene and p-cymene, were constantly present in the essential oils analysed, but always in lower amounts than those of the phenols, according to the results described by a previous paper [17]. The oxygenated monoterpenes represent 5.60% (F), 21.60% (S) and 33.70% (SG) of the oils. In the oils were totally detected 22 sesquiterpene hydrocarbons that ranged between 21.60% (F) and 12.70% (S). In all oils, γ-muurolen (4.48%-2.59%), (E)-β-caryophyllene (4.29%-2.11%), β-bisabolene (4.13%-2.51%) and δ-cadinene (3.17%-0.09%) were the most abundant sesquiterpenes of this fraction being the other components present in lower amounts, traces or absent. Oxygenated sesquiterpenes the most abundant were α-cadinol (4.02%-1.06%) and spathulenol (3.90%-1.20%).

Table 1. Essential oil composition (% of total) of aerial parts of *O. vulgare* ssp. *hirtum* (Lamiaceae) growing wild in Southern Italy.

| K<sup>a</sup> | K<sup>b</sup> | Compound   | Identification | F<sup>d</sup>      | S<sup>d</sup>      | SG<sup>d</sup> |
|---------------|---------------|-------------|----------------|-------------------|-------------------|---------------|
| 925           | 1013          | Tricyclene  | LRI, MS        | 0.29±0.02         | 0.20±0.01         | 0.10±0.01     |
| 928           | 1035          | α-Thujene   | LRI, MS        | 0.11±0.01         | 0.28±0.01         | 0.21±0.01     |
| 938           | 1075          | α-Pinene    | LRI, MS, Co-GC | 0.19±0.03         | 0.42±0.01         | 0.19±0.02     |
| 945           | 1056          | Camphene    | LRI, MS, Co-GC | 0.50±0.02         | t                 | 0.22±0.01     |
| 973           | 1132          | Sabinene    | LRI, MS, Co-GC | 0.20±0.01         | 0.28±0.04         | 0.88±0.03     |
| 978           | 1118          | β-Pinene    | LRI, MS, Co-GC | 0.11±0.01         | 0.32±0.03         | 0.40±0.01     |
| 980           | 1154          | 1-Octen-3-ol| LRI, MS        | 0.30±0.04         | 0.30±0.01         | t             |
| 983           | 1253          | Octan-3-one | LRI, MS        | 0.30±0.04         | 0.30±0.01         | 0.10±0.01     |
| 993           | 1173          | Myrcene     | LRI, MS, Co-GC | 0.70±0.09         | 0.90±0.06         | 2.80±0.20     |
| 1001          | 1146          | δ<sup>2</sup>-Carene | LRI, MS | 0.11±0.01         | 0.30±0.02         | 0.22±0.01     |
| 1005          | 1150          | α-Phellandrene | LRI, MS, Co-GC | 0.29±0.02         | 0.50±0.03         | 0.08±0.00     |
| 1008          | 1160          | δ<sup>3</sup>-Carene | LRI, MS | 0.27±0.02         | 1.10±0.10         | 0.19±0.02     |
| \(K_i^a\) | \(K_i^b\) | Compound                  | Identification   | \(I^d\)   | \(S_i^d\) | \(S_G^d\)  |
|--------|--------|---------------------------|------------------|-----------|-----------|------------|
| 1013   | 1189   | \(\alpha\)-Terpinene     | LRI, MS, Co-GC   | 0.33±0.03 | 0.50±0.03 | 0.41±0.03  |
| 1025   | 1278   | \(p\)-Cymene              | LRI, MS, Co-GC   | 2.81±0.20 | 1.25±0.3  | 2.01±0.10  |
| 1029   | 1218   | \(\beta\)-Phellandrene   | LRI, MS, Co-GC   | 0.19±0.02 | 0.15±0.00 | 0.09±0.01  |
| 1030   | 1205   | Limonene                  | LRI, MS, Co-GC   | 0.27±0.01 | 1.21±0.3  | 2.36±0.20  |
| 1034   | 1213   | 1,8-Cineole               | LRI, MS, Co-GC   | 0.50±0.03 | 0.50±0.04 | 0.60±0.03  |
| 1038   | 1243   | (Z)-\(\beta\)-Ocimene    | LRI, MS          | 0.83±0.04 | 0.69±0.01 | 4.64±0.40  |
| 1049   | 1262   | (E)-\(\beta\)-Ocimene    | LRI, MS          | 0.22±0.01 | 1.71±0.30 | 4.10±0.20  |
| 1057   | 1256   | \(\gamma\)-Terpinene     | LRI, MS, Co-GC   | 2.38±0.40 | 4.59±0.80 | 4.90±0.10  |
| 1086   | 1265   | Terpinolene               | LRI, MS          | 1.80±0.5  | 1.20±0.1  | 0.50±0.03  |
| 1097   | 1553   | Linalool                  | LRI, MS, Co-GC   | 2.87±0.30 | 4.10±0.2  | 12.50±0.7  |
|        |        | \(cis\)-\(p\)-Menth-2-en-1-ol | LRI, MS         | 0.13±0.01 | t         |            |
| 1167   | 1718   | Borneol                   | LRI, MS, Co-GC   | 0.33±0.01 | 0.29±0.02 | t          |
| 1169   | 1706   | \(\alpha\)-Terpineol     | LRI, MS          | 1.07±0.20 | 0.41±0.01 | 0.80±0.01  |
| 1239   | 1607   | Thymol methyl ether      | RI, MS, Co-GC    | 3.81±0.60 | 2.27±0.20 | 1.11±0.10  |
| 1245   | 1975   | Carvacrol methyl ether   | LRI, MS, Co-GC   | 1.19±0.40 | 4.63±0.10 | 0.79±0.03  |
| 1259   | 1665   | Linalyl acetate          | LRI, MS, Co-GC   | 0.48±0.04 | 1.20±0.1  | 15.90±0.5  |
| 1293   | 2198   | Thymol                   | LRI, MS, Co-GC   | 18.21±0.80| 26.75±0.70| 3.24±0.30  |
| 1299   | 2239   | Carvacrol                | LRI, MS, Co-GC   | 21.89±0.70| 6.45±0.65 | 0.46±0.02  |
| 1348   | 1466   | \(\alpha\)-Cubebene      | RI, MS           | 0.20±0.01 | 0.10±0.01 | 0.10±0.00  |
| 1353   | 2186   | Eugenol                  | RI, MS, Co-GC    | 0.20±0.02 | t         |            |
| 1356   | 1868   | Thymyl acetate           | LRI, MS          | 0.14±0.01 | 0.31±0.00 | 0.49±0.01  |
| 1367   | 1890   | Carvacryl acetate        | LRI, MS          | 0.26±0.02 | 0.09±0.02 | 0.21±0.02  |
| 1372   | 1493   | \(\alpha\)-Ylangene      | LRI, MS          | 0.27±0.01 | t         |            |
| 1377   | 1497   | \(\alpha\)-Copaene       | LRI, MS          | 0.29±0.03 | 0.15±0.01 | t          |
| 1382   | 1549   | \(\beta\)-Cubebene       | LRI, MS          | 0.21±0.04 | 0.25±0.02 | 0.10±0.02  |
| 1385   | 1535   | \(\beta\)-Bourbonene     | LRI, MS          | 0.33±0.05 | 0.20±0.01 | 0.60±0.01  |
| 1387   | 1600   | \(\beta\)-Elemene        | LRI, MS          | 0.10±0.01 | 0.10±0.00 | 0.20±0.00  |
| 1415   | 1612   | (E)-\(\beta\)-Caryophyllene | LRI, MS        | 3.72±0.51 | 2.11±0.10 | 4.29±0.3   |
| 1432   | 1612   | \(\beta\)-Gurjunene      | LRI, MS          | 0.27±0.02 | 0.09±0.01 | 0.19±0.01  |
| 1432   | 1650   | \(\gamma\)-Elemene       | LRI, MS          | 0.29±0.03 | 0.22±0.02 | 0.15±0.01  |
| 1437   | 1628   | Aromadendrene            | LRI, MS          | 0.21±0.00 | 0.19±0.02 | t          |
| 1455   | 1689   | \(\alpha\)-Humulene      | LRI, MS          | 1.71±0.20 | 1.48±0.20 | 1.35±0.20  |
| 1463   | 1662   | \(allo\)-Aromadendrene  | LRI, MS          | 0.19±0.03 | 0.11±0.00 | 0.50±0.04  |
| 1477   | 1726   | Germacrene D             | LRI, MS          | 0.13±0.00 | 0.41±0.02 | 2.11±0.30  |
| 1478   | 1704   | \(\gamma\)-Murolene      | LRI, MS          | 4.48±0.58 | 2.59±0.20 | 3.61±0.20  |
| 1492   | 1756   | Bicyclogermacrene        | LRI, MS          | 0.35±0.06 | 0.13±0.03 | t          |
| 1494   | 1740   | Valencene                | LRI, MS          | 0.25±0.05 | 0.17±0.02 | t          |
| 1503   | 1740   | \(\alpha\)-Murolene      | LRI, MS          | 0.22±0.01 | 0.20±0.01 | 0.39±0.01  |
Table 1. Cont.

| Ki^a | Ki^b | Compound       | Identification | F^d   | S^d   | SG^d |
|------|------|----------------|---------------|-------|-------|------|
| 1510 | 1743 | β-Bisabolene   | LRI, MS       | 4.13±0.42 | 2.81±0.20 | 2.51±0.20 |
| 1515 | 1776 | γ-Cadinene     | LRI, MS       | 0.81±0.06 | 0.29±0.01 | 0.35±0.01 |
| 1526 | 1773 | δ-Cadinene     | LRI, MS       | 3.17±0.51 | 0.99±0.1  | 2.09±0.30 |
| 1532 | 1745 | α-Cadinene     | LRI, MS       | 0.18±0.01 | t      | 0.21±0.00 |
| 1544 | 1854 | Germacrene B   | LRI, MS       | 0.09±0.01 | 0.11±0.01 | 0.15±0.01 |
| 1565 | 2057 | Ledol          | LRI, MS       | t      | t      | 0.10±0.00 |
| 1577 | 1250 | Spathulenol    | LRI, MS       | 3.90±0.40 | 1.20±0.20 | 1.20±0.01 |
| 1579 | 2008 | Caryophyllene oxide | LRI, MS | 1.01±0.09 | 0.60±0.04 | 1.20±0.1 |
| 1636 | 2183 | γ-Eudesmol     | LRI, MS       | 0.21±0.03 | 0.14±0.00 | 0.38±0.03 |
| 1640 | 2158 | t-Cadinol      | LRI, MS       | 2.10±0.50 | 0.15±0.00 | 0.19±0.02 |
| 1642 | 2209 | t-Muurolol     | LRI, MS       | t      | 0.05±0.01 | 1.51±0.20 |
| 1652 | 2235 | α-Cadinol      | LRI, MS       | 1.69±0.09 | 1.06±0.2  | 4.02±0.3 |
| 1668 | 2219 | α-Bisabolol    | LRI, MS       | 0.19±0.01 | t      |       |
|      |      | TOTAL          |               | 93.90  | 94.00  | 91.80 |

F: Furore sample; S: Sanza sample; SG: San Giovanni a Piro sample. The values are the mean of three replicates±SD. ^a: HP 5MS column; ^b: HP Innowax column ; ^c: LRI = linear retention index, MS = mass spectrum, Co-GC = co-injection with authentic compound; ^d: Mass of compounds in mg/100 mg oil; t, trace (<0.05%); mean value ± standard error, n, three independent determinations.

The available literature [2] reports the presence of a carvacrol/thymol chemotype of *O. vulgare* ssp. *hirtum*; the others two chemotypes were described for the first time. Some papers describe the essential oil composition of *O. vulgare* ssp. *hirtum* from different geographic areas. Russo et al. [2] reported four chemotypes for this species, growing in Calabria (Southern Italy), on the basis of their phenolic content: thymol, carvacrol, thymol/carvacrol and carvacrol/thymol chemotypes, with the majority of samples belonging to a thymol chemotype. Kokkini et al. [16] studied the essential oils from *O. vulgare* ssp. *hirtum* plants collected in late autumn from six localities of three distinct geographic areas of Greece. They reported that oils of plants from the Northern part of Greece were rich in thymol, whereas those from the Southern part of the country were rich in carvacrol. Several samples rich in carvacrol were found also in Bulgaria [22].

Generally, chemotypes form “biochemical varieties” or “physiological forms” in botanical species, each of which with a specific enzymatic equipment. These species are genetically codified and direct their biosynthesis to the preferential formation of a definite compound. In the case of phenolic compounds, the metabolic pathway is through the autooxidative conversion of γ-terpinene to p-cymene followed by hydroxylation of p-cymene to thymol or carvacrol [23]. The phenols content, generally, is high during flowering stage in phenol-type origanum plant, as reported [24,25].

The characterization of habitat is of fundamental importance to understand species distribution. In a definite geographical area, the factors that weight heavily on chemotypes differentiation are mainly related to intrinsic factors such as sexual polymorphism or genetic mechanism, but for the phenolic essences, environmental conditions are able to influence biosynthetic pathway. At this regard, it is interesting note that the samples studied were collected in areas with different sun exposure. In fact, Furore is located in a sunny position, front the sea, Sanza is located in an internal zone, far from the...
sea, with temperatures lower than the other two places of sample collection, and San Giovanni a Piro is located quite near the sea. Also the season and the characteristic of plant (fresh or dried) can determinate noticeable differences in the total oil content and the concentration of the main oil components: in particular, the proportion of carvacrol has been shown to be much higher in the summer; in the autumn, \( p \)-cymene predominates [16,17,26].

Very few papers have reported an oregano chemotype characterized by the presence of linalyl acetate/linalool but never in \( O. \) vulgare ssp. \( hirtum \). In fact, Perez et al. [27] reported linalool as the main volatile component of \( O. \) vulgare ssp. \( virens \), characterized by a high quantity of linalool and a low quantity of thymol. D’Antuono et al. [28] reported a Northern Italian population of \( O. \) vulgare L. rich in linalool. On the other hand, Mockute et al. [29] showed that the main constituents of the essential oil of \( O. \) vulgare ssp. \( viride \), wild in Iran, were linalyl acetate, \( \beta \)-caryophyllene and sabinene. Data reported in this work should help to throw light in the apparent complex chemotaxonomy of the genus \( Origanum \).

**Antimicrobial activity**

The Minimum Inhibitory Concentration (MIC) and the Minimum Bacterial Concentration MBC values of the essential oils against 10 selected microorganisms are reported in Table 2. The essential oils showed action mainly against the Gram-positive pathogens, among which \( S. \) epidermidis was the most affected. Among Gram-negative bacteria, only \( E. \) coli was affected by the oil F. The oil F and S resulted more active than oil SG and presumably this activity is related to phenolic components, such as thymol, carvacrol, carvacrol methyl ether, though part of the activity could result from the synergistic presence of minor active constituents, such as \( \gamma \)-terpinene and \( p \)-cymene.

**Table 2.** MIC and MBC values (\( \mu \)g/mL) of essential oils from \( O. \) vulgare L. ssp. \( hirtum \) (Link) Ietswaart growing wild in Campania and MIC of reference antibiotic. Results are the mean of three experiments.

| Bacterial strain | \( F \) | \( S \) | \( SG \) | G |
|------------------|--------|--------|--------|---|
|                  | MIC    | MBC    | MIC    | MBC | MIC    | MBC    | MIC    | MBC | \( \mu \)g/mL |
| Bacillus cereus  | 50     | 50     | 50     | 50   | 50     | 100    | 1.56   |
| ATCC 11778       |        |        |        |      |        |        |        |
| Bacillus subtilis| 50     | 50     | 50     | 100  | 50     | 100    | 1.56   |
| ATCC 6633        |        |        |        |      |        |        |        |
| Staphylococcus aureus | 50     | 50     | 50     | 50   | 100    | 3.12   |
| ATCC 2592        |        |        |        |      |        |        |        |
| Staphylococcus epidermidis | 25     | 25     | 25     | 50   | 50     | 6.25   |
| ATCC 12228       |        |        |        |      |        |        |        |
| Streptococcus faecalis | 50     | 100    | 50     | 100  | 100    | >100   |
| ATCC 29212       |        |        |        |      |        |        |        |
| Escherichia coli  | 50     | 100    | 100    | 100  | 100    | 3.12   |
| ATCC 25922       |        |        |        |      |        |        |        |
Table 2. Cont.

| Bacterial strain       | F MIC | F MBC | S MIC | S MBC | SG MIC | SG MBC | G    |
|------------------------|-------|-------|-------|-------|--------|--------|------|
| *Proteus mirabilis*    |       |       |       |       |        |        |      |
| ATCC 25933             | 100   | 100   | 100   | 100   | >100   | 100    |      |
| *Proteus vulgaris*     |       |       |       |       |        |        |      |
| ATCC 13315             | 100   | >100  | 100   | 100   | >100   | 100    |      |
| *Pseudomonas aeruginosa* |     |       |       |       |        |        |      |
| ATCC 27853             | >100  | >100  | >100  | 12.5  |        |        |      |
| *Salmonella typhi Ty2* |       |       |       |       |        |        |      |
| ATCC 19430             | 100   | 100   | 100   | 100   | >100   | >100   |      |

F: Furore sample; S: Sanza sample; SG: San Giovanni a Piro sample; G = gentamycine.

The antibacterial activity results seem to be in accordance with previous reports indicating that the essential oils, rich in phenolic compounds, possess high levels of antimicrobial activity [30-33]. Ložienė et al., [34] have reported the antimicrobial activity of phenolic compounds, such as carvacrol and thymol. It is noteworthy that has been suggested that phenolic derivatives can cause membrane-disrupting activities [35]. Linalol proved to be a very active compound: in fact, Mazzanti et al., [36] reported that such component inhibited the growth of different microorganism; linalyl acetate showed bacteriostatic activity [37]. The lower antimicrobial activity of the oil SG should also be due to a synergistic presence of minor active constituents, such as α-terpineol, thymol, γ-terpinene and p-cymene [38-43].

**Experimental**

**Plant material**

Samples of *Origanum vulgare* L. ssp. *hirtum* (Link) Ietswaart were collected from populations growing wild in different areas of Salerno province (Campania, Southern Italy) in June 2008: Furore, 600 m s. l. (F), Sanza, 500 m s. l. (S) and San Giovanni a Piro, 450 m s. l. (SG). Voucher of each sample were stored in the Herbarium of the Salerno University: Sa 05/08, Sa 06/08 and Sa 07/08, respectively for F, S and SG. The representative homogeneous sample of each population was collected during “balsamic time” corresponding to the flowering stage. The plant material used for the isolation of the essential oil was air-dried at room temperature.

**Oil extraction**

Lots of twenty grams of dried inflorescences were hydrodistilled for three hours in a Clevenger type apparatus, as previously described [44].

**Gas Chromatography**

Gas Chromatography (GC) analyses were carried out using a Perkin-Elmer Sigma-115 gas chromatograph equipped with a data handling system and a flame ionization detector (FID). Separation
was achieved by a fused-silica capillary column HP 5MS, 30 m length, 0.25 mm internal diameter, 0.25 µm film thickness. The operating conditions were as follows: injector and detector temperatures, 250 °C and 280 °C, respectively; oven temperature programme: 5 min isothermal at 40 °C, subsequently at 2 °C/min up to 250 °C and finally raised to 270 °C at 10 °C/min. Helium was used as the carrier gas (1 mL/min). Diluted samples (1/100 v/v, in n-pentane) of 1 µL were manually injected at 250 °C, and in the splitless mode. Analysis was also made by using a fused silica HP Innowax polyethyleneglycol capillary column (50 m x 0.20 mm i.d.; 0.20 µm film thickness). The percentage composition of the oils was computed by the normalization method from the GC peak areas. The analysis have been carried out in triplicate and the results are expressed as mean ± SD.

**Gas Chromatography - Mass Spectrometry**

Gas Chromatography-Mass Spectrometry (GC-MS) analysis was performed using an Agilent 6850 Ser. A apparatus, equipped with a fused silica HP-5 capillary column (30 m x 0.25 mm i.d.; film thickness 0.33 µm), linked on line with an Agilent MSD 5973 Mass Selective Detector; ionization energy 70 eV, multiplier voltage 2000 V. Mass spectra were scanned in the range 35-450 amu, scan time 5 scans/s. Gas chromatographic conditions were as given above, transfer line was kept at 295 °C.

The oil components were identified from their GC retention indices, with either those of the literature [45-46] or with those of authentic compounds available in our laboratories. The identity of the components was assigned by comparing their linear retention indices, relative to C₈-C₂₈ n-alkanes, under the same operating conditions. Further identification was made by comparison of their MS spectra on both columns, with either stored in NIST 02 and Wiley 275 libraries or with mass spectra from the literature [45-47] and our homemade library. The analyses were carried out in triplicate and the results are expressed as mean ± SD.

**Antibacterial activity**

The antibacterial activity was evaluated by determining the minimum inhibitory concentration (MIC) and the minimum bactericidal concentration (MBC), using the broth dilution method [48-50]. Ten bacterial species, selected as representative of the Gram+ and Gram- classes, were tested: *Bacillus cereus* (ATCC 11778), *Bacillus subtilis* (ATCC 6633), *Staphylococcus aureus* (ATCC 25923), *Staphylococcus epidermidis* (ATCC 12228), *Streptococcus faecalis* (ATTC 29212), *Escherichia coli* (ATCC 25922), *Proteus mirabilis* (ATCC 25933), *Proteus vulgaris* (ATCC 13315), *Pseudomonas aeruginosa* (ATCC 27853), *Salmonella typhi* Ty2 (ATCC 19430). The strains were maintained on Tryptone Soya agar (Oxoid, Milan, Italy); for the antimicrobial tests, Tryptone Soya broth (Oxoid, Milan, Italy) was used. In order to facilitate the dispersion of the oil in the aqueous nutrient medium, it was diluted with Tween 20 at a concentration of 10%. Each strain was tested with sample that was serially diluted in broth to obtain concentrations ranging from 100 µg/mL to 0.8 µg/mL. The sample was previously sterilized with a 0.20 µm Millipore filter. The sample was stirred, inoculated with 50 µL of physiological solution containing 5 x 10⁶ microbial cells, and incubated for 24 h at 37 °C. The MIC value was determined as the lowest concentration of the sample that not permit any visible growth of the tested microorganism after incubation. Control, containing only Tween 20 instead of the essential oil, was not toxic to the microorganisms. Cultures, containing only sterile physiologic
solution Tris buffer, were used as positive control. MBC was determined by subculture of the tubes with inhibition in 5 mL of sterile nutrient broth. After incubation at 37 °C the tubes were observed. When the germs don’t grow, the sample denoted a bactericidal action. Oil samples were tested in triplicate and the experiment was performed three times. The results are expressed as mean ± SD. Gentamycine was used as reference agent.

Conclusions

Essential oils are presently regarded as useful in food technology [51], in fact, their use in food preparation accomplishes both food flavouring and food preservation. Data obtained clearly showed the inhibitory activity of the essential oils tested against pathogenic bacteria. The available literature [52-53] shows that essential oils are natural preservatives in food and/or pharmaceutical industry: this use represents a viable and safe way to decrease the utilisation of synthetic food preservatives, due to their positive effects both on safety and shelf life.

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**Sample Availability:** Samples of the essential oils are available from the authors.

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