# Chemistry and Antigerminative Activity of Essential Oils and Monoterpenoids from Mediterranean Plants

Laura De Martino[1]*, Emilia Mancini[1], Aurelio Marandino[1], Luiz Fernando Rolim de Almeida[2] and Vincenzo De Feo[1]

[1]*Dipartimento di Scienze Farmaceutiche e Biomediche, Università degli Studi di Salerno, Via Ponte Don Melillo, 84084 Fisciano (Salerno), Italy;* [2]*Departamento de Botânica, Instituto de Biociências de Botucatu, UNESP - Campu de Botucatu, Distrito de Rubião Júnior, S/N, 18.618-000, Botucatu-SP, Brazil*

**Abstract:** The Mediterranean flora is characterized by the abundance of aromatic plants. The feature differentiating these plants from all others, in spite of the fact that they belong to many different families, is the production of chemically related secondary compounds, the low molecular weight and volatile isoprenoids. This remarkable presence of aromatic species is important in determining the phytotoxic potential within this ecosystem. Such plants make a significant contribution to phryganic Mediterranean ecosystems both in terms of species number and biomass. Thus, the essential oils play an important role in this ecological context. Mediating various processes in the frame of an ecosystem, they become indirectly beneficial to the plants, considering their involvement in processes of adaptative character in Mediterranean ecosystem.

For this reason, our research group carried out a series of studies on the possible phytotoxic properties of aromatic plants that, being rich in active principles, are considered a primary source of potential allelochemicals.The focus of this overview is direct to have an overall idea about the chemistry and antigerminative activity of essential oils of some Mediterranean aromatic plants and their main constituents.

**Keywords:** Mediterranean flora, aromatic plants, essential oils, chemistry, antigerminative activity, monoterpenes.

## INTRODUCTION

Essential oils are concentrated natural products, characterized by a strong odour and are formed by aromatic plants as secondary metabolites. The term 'essential oil' was used for the first time in the 16$^{th}$ century by Paracelsus von Hohenheim, who named the effective component of a drug 'Quinta essential' [1]. They are liquid, volatile, limpid and coloured, soluble in lipids and in organic solvents with a generally lower density than that of water. They can be present in all plant organs, i.e. buds, flowers, leaves, stems, twigs, seeds, fruits, roots, wood or bark, and are stored in secretory cells, cavities, canals, epidermic cells or glandular trichomes. They are usually obtained by steam or hydrodistillation, first developed in the Middle Ages by Arabs, but several other techniques can be used to extract essential oils from the aromatic plants, i.e. solvent extraction, expression under pressure, supercritical fluid and subcritical water extractions. Essential oils are extracted from various aromatic plants generally localized in temperate to warm countries like Mediterranean and tropical countries, where they represent an important part of the traditional pharmacopoeia. Known for their antiseptic, i.e. bactericidal, virucidal and fungicidal, and medicinal properties and their fragrance, they are used in preservation of foods and as antimicrobial, analgesic, sedative, anti-inflammatory, spasmolytic and locally anesthesic remedies [2].

*Address correspondence to this author at the Dipartimento di Scienze Farmaceutiche e Biomediche, Università degli Studi di Salerno, Via Ponte Don Melillo, 84084 Fisciano (Salerno), Italy; Tel: +39089968292; Fax: +39089969602; E-mail: ldemartino@unisa.it

In nature, essential oils play an important role in the protection of the plants as antibacterials, antivirals, antifungals, insecticides and also against herbivores by reducing their appetite for such plants. They also may attract some insects to favour the dispersion of pollens and seeds, or repel undesirable others [2]. Moreover, essential oils play a pivotal role in plant interactions with the environment, for self defense, sexual attraction, symbiosis, and development [3]. The production and accumulation of secondary metabolites, which inhibit and/or stimulate germination and development of other plants (allelochemicals), is an important mechanism in the interactions between plants. This chemical interaction is probably of widespread significance in the functioning of natural communities. In fact, a number of plants have inhibitory effects on the growth of neighbouring or successional plants by releasing chemicals into the soil, either as exudates from living tissues or by decomposition of plant residues [4-6]. Thus, the study of compounds produced by plants, which inhibit or stimulate the germination and the development of other plants, is important for understanding the mechanisms of the ecological interaction [7].

One of the best known and well-studied examples of allelopathy is the "*Salvia* phenomenon". The first studies that demonstrated the presence of volatile growth inhibitors produced by *Salvia* species were carried out on *Salvia leucophylla* and *S. apiana* by Muller and co-workers [8-12]. Authors showed that when cucumber seedlings were placed in proximity to crushed leaves of the two *Salvia* species, their root growth was markedly inhibited, and this inhibition was increased as the amount of leaves was increased. Successively, the same authors suggested that the inhibition of

**1875-6646/12 $58.00+.00** 

growth of annual grassland species in and about colonies of *Salvia* species and the gradually decreasing inhibition of herbs extending 9 m out into grassland from *Salvia* patches, were due to the production of volatile terpenes, particularly camphor and cineole [9-12].

Volatile oils and their constituents are today being explored for weed and pest management and are viewed as an important source of lead molecules in agriculture [13]. Bioactive terpenoids constitute an important part of the defensive mechanisms of a large number of organisms and represent a fairly untapped source of active compounds of potential use both in the agricultural and pharmaceutical fields [14]. In fact, a large number of highly phytotoxic allelochemicals are derived from the terpenoid pathway [15] and the phytotoxicity of essential oils has been investigated in various plant tissues which contains or produce these compounds [16-18].

The Mediterranean flora is characterized by the abundance of aromatic plants. The feature differentiating these plants from all others, in spite of the fact that they belong to many different families, is the production of chemically related secondary compounds, the low molecular weight and volatile isoprenoids. This remarkable presence of aromatic species is important in determining the phytotoxic potential within this ecosystem [19]. Such plants make a significant contribution to phryganic Mediterranean ecosystems both in terms of species number and biomass [20]. Thus, the essential oils play an important role in this ecological context. Mediating various processes in the frame of an ecosystem, they become indirectly beneficial to the plants, considering their involvement in processes of adaptative character in Mediterranean ecosystem [19]. Recently, volatile sesquiterpenes that emanate from roots of some invasives bushes were shown to inhibit the seedling growth of associated vegetation, and thus possibly help in successful invasion in the introduced sites [13].

For this reason, our research group carried out a series of studies on the possible phytotoxic properties of aromatic plants [7, 21-29] that, being rich in active principles, are considered a primary source of potential allelochemicals.The focus of this overview is direct to have an overall idea about the chemistry and antigerminative activity of essential oils of some Mediterranean aromatic plants and their main constituents.

We studied the *in vitro* possible phytotoxicity of the essential oils from 12 Mediterranean plants, belonging to three different families, *Hyssopus officinalis* L. (hyssop), *Lavandula angustifolia* Mill. (lavender), *Majorana hortensis* L. (marjoram), *Melissa officinalis* L. (lemon balm), *Ocimum basilicum* L. (basil), *Origanum vulgare* L. (oregano), *Salvia officinalis* L. (sage), *Thymus vulgaris* L. (thyme) (Lamiaceae), *Carum carvi* L. (caraway), *Foeniculum vulgare* Mill. (fennel), *Pimpinella anisum* L. (anise) (Apiaceae), *Verbena officinalis* L. (vervain) (Verbenaceae) against the germination and radicle growth of the crop species *Raphanus sativus* L. cv. Saxa (radish) and *Lepidium sativum* L. (garden cress), comparing the effects of the oils in light of their chemical composition [7, 24, 27].

Furthermore, similar studies about the chemical composition and the possible antigerminative activity of different essential oils from plants belonging to Lamiaceae [*Nepeta curviflora* Boiss., *Nepeta nuda* L. ssp. *albiflora*, *Salvia hierosolymitana* Boiss., *Salvia multicaulis* Vahl. var. *simplicifolia* Boiss., *Salvia africana* L., *Salvia elegans* Vahl, *Salvia greggii* A. Gray, *Salvia mellifera* Greene, *Salvia munzii* Epling, *Teucrium arduini* L., *Teucrium maghrebinum* Greuter et Burdet, *Teucrium montbretii* Benth. ssp. *heliotropiifolium* (Barbey) Davis, *Teucrium polium* L. ssp. *capitatum* (L.) Arcangeli], Guttiferae (*Hypericum perforatum* L., *Hypericum perfoliatum* L. and *Hypericum hircinum* L.) and Asteraceae [*Helichrysum italicum* (Roth)] families [21-23, 25, 26, 28, 29] were carried out.

Table **1** shows the composition of the 12 essential oils, object of our study. The main constituent of *P. anisum* and *F. vulgare* essential oils was *cis*-anethole, which represented 97.1% and 76.3% of the whole oils, respectively. The dominant components in *C. carvi* oil were estragole, limonene, β-pinene and *trans*-pinocamphone. Vervain essential oil was mainly constituted by citral and isobornyl formate. β-Pinene, *iso*-pinocamphone and *trans*-pinocamphone were the most abundant components of *H. officinalis* essential oil. Linalol (23.1%) and linalyl acetate (44.4%) represented the main components of the oil of *L. angustifolia*. Marjoram essential oil was mainly constituted by 1,8-cineole (33.5%) and α-pinene (9.0%). The main constituents of *M. officinalis* essential oil were (-)-citronellal (39.6%), and in minor measure carvacrol and *iso*-menthone; *iso*-pinocamphone (35.1%) and carvone (39.7%) were the predominant components of *O. basilicum* essential oil. In *O. vulgare* and *T. vulgaris* oils, *o*-cymene and carvacrol were the main constituents, accounting, respectively, for 41.9% and 44.0%, in oregano, and 56.2% and 24.4% in thyme oil. Sage essential oil was mainly constituted by *trans*-thujone (37.9%).

The oils were tested against germination and radical elongation of radish and garden cress seeds (Tables **2** and **3**). The germination of *Lepidium sativum* was drastically affected by the essential oils of balm, caraway, hyssop, thyme and vervain, with a 100% inhibition. Caraway, vervain, sage and marjoram essential oils influenced, in a significative way, the radicle elongation of this seed, at all tested doses. Moreover, some oils (anise, basil), at the lowest dose, promoted the germination and/or radicle elongation of garden cress. Generally, garden cress is the less sensitive seed. Almost all oils, except anise, basil and fennel, inhibited by 100% the germination of *R. sativus*, at the highest dose tested.

In addition, caraway, hyssop and sage oils inhibited, in a significative way, the germination of radish, at all doses tested. The radicle growth of the same seeds was affected by 100% by vervain, caraway, oregano, thyme, hyssop and lavender essential oils. Moreover, all oils cited above, except lavender, were active towards radicle elongation, at all doses.

The antigerminative activity was assessed by performing two different methods, by dipping and by volatilization: infact, an other test, for evaluating the potential phytoxicity of essential oils, was carried only through their vaporization. Seed germination process and radical elongation were

**Table 1. Essential Oil Compositions (%) of *Hyssopus officinalis, Lavandula angustifolia, Majorana hortensis, Melissa officinalis, Ocimum basilicum, Origanum vulgare, Salvia officinalis, Thymus vulgaris, Carum carvi, Foeniculum vulgare, Pimpinella anisum, Verbena officinalis***

| Compound | Ki[a] | Ki[b] | *P. anisum*[c] % | *M. offcinalis* % | *O. basilicum* % | *C. carvi* % | *F. vulgare* % | *H. offcinalis* % | *L. angustifo-* % | *M. hortensis* % | *O. vulgare* % | *S. officinalis* % | *T. vulgaris* % | *V. officinalis* % | Identifi-cation[d] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| α-Thujene | 930 | 1035 | --- | 0.1±0.0 | t | 0.2±0.0 | t | 0.4±0.0 | 0.2±0.0 | 0.1±0.0 | 0.5±0.0 | 0.4±0.0 | t | --- | 1, 2 |
| α-Pinene | 938 | 1032 | 0.3±0.0 | 0.9±0.0 | 0.3±0.0 | 0.5±0.2 | 1.8±0.1 | 1.0±0.0 | --- | 9.0±0.1 | 0.4±0.0 | 4.4±0.1 | 2.5±0.1 | 0.2±0.0 | 1, 2, 3 |
| (-)-Camphene | 953 | 1076 | --- | --- | --- | --- | --- | 0.2±0.0 | 0.7±0.0 | 0.3±0.0 | 0.2±0.0 | 4.1±0.0 | 1.0±0.1 | --- | 1, 2, 3 |
| Sabinene | 973 | 1132 | t | t | 0.3±0.0 | 1.0±0.1 | t | 1.4±0.9 | t | 1.1±0.1 | t | 0.4±0.0 | t | 0.5±0.0 | 1, 2, 3 |
| Hepten-3-one | 975 | | --- | t | --- | --- | --- | --- | --- | t | --- | --- | --- | 0.2±0.1 | 1, 2 |
| β-Pinene | 978 | 1118 | --- | 0.4±0.1 | 0.5±0.0 | 7.4±0.4 | 0.5±0.1 | 18.2±0.0 | --- | 3.8±0.9 | 0.2±0.0 | 2.5±0.1 | --- | t | 1, 2, 3 |
| *cis*-Pinane | 980 | 1073 | --- | --- | 0.1±0.0 | 0.1±0.0 | --- | --- | 0.1±0.0 | --- | 0.1±0.0 | --- | --- | --- | 1, 2 |
| Verbenene | 982 | 1131 | --- | t | t | t | t | 0.1±0.0 | t | t | t | t | t | --- | 1, 2 |
| Myrcene | 993 | 1174 | --- | 0.1±0.0 | 0.3±0.1 | 0.7±0.1 | 0.2±0.1 | 1.8±0.2 | 0.3±0.0 | 0.7±0.3 | 0.5±0.0 | 0.5±0.1 | 0.1±0.0 | --- | 1, 2, 3 |
| α-Phellandrene | 995 | 1176 | 0.1±0.0 | t | t | t | 0.3±0.0 | t | 0.2±0.0 | 0.2±0.0 | 0.1±0.0 | t | t | --- | 1, 2, 3 |
| Δ3-Carene | 997 | 1153 | 0.1±0.0 | --- | --- | --- | 0.3±0.1 | --- | 0.3±0.1 | 0.3±0.0 | 0.2±0.0 | --- | --- | --- | 1, 2, 3 |
| α-Terpinene | 1012 | 1188 | --- | 0.1±0.1 | t | t | t | 0.2±0.1 | t | 0.1±0.0 | 0.5±0.0 | t | 0.1±0.0 | t | 1, 2, 3 |
| *o*-Cymene | 1020 | 1187 | 0.1±0.0 | 2.3±0.9 | 0.1±0.0 | 0.2±0.0 | 0.7±0.1 | 0.2±0.0 | 0.6±0.1 | 2.6±0.9 | 41.9±0.1 | 2.5±0.2 | 56.2±0.2 | 0.1±0.0 | 1, 2, 3 |
| *p*-Cymene | 1024 | 1280 | --- | 0.6±0.0 | --- | 0.1±0.1 | 0.3±0.0 | --- | 0.3±0.0 | 0.4±0.1 | 0.1±0.0 | 1.2±0.1 | 0.1±0.0 | --- | 1, 2, 3 |
| β-Phellandrene | 1029 | 1218 | t | 0.3±0.0 | 0.3±0.0 | 0.6±0.2 | 0.4±0.1 | 1.8±0.2 | 0.1±0.0 | 9.1±0.5 | 0.1±0.0 | 1.0±0.0 | 0.2±0.1 | 0.7±0.2 | 1, 2, 3 |
| Limonene | 1030 | 1203 | --- | 1.4±0.3 | 0.4±0.0 | 14.3±0.5 | 1.5±0.5 | 1.3±0.7 | 0.3±0.0 | 6.4±0.5 | 0.3±0.0 | 1.4±0.0 | 0.6±0.0 | 2.3±0.9 | 1, 2, 3 |
| 1,8-Cineole | 1034 | 1213 | --- | 0.2±0.0 | 0.5±0.1 | 0.1±0.0 | t | 0.2±0.0 | t | 33.5±0.3 | 0.6±0.1 | 4.2±0.3 | t | 0.4±0.1 | 1, 2 |
| (Z)-β-Ocimene | 1038 | 1246 | t | t | 0.1±0.0 | 0.1±0.0 | t | 0.3±0.0 | 1.7±0.3 | 0.1±0.0 | t | t | t | t | 1, 2, 3 |
| (E)-β-Ocimene | 1049 | 1280 | --- | t | 1.2±0.0 | 0.3±0.1 | t | 1.0±0.0 | 0.6±0.1 | 0.2±0.1 | t | t | t | 0.3±0.1 | 1, 2, 3 |
| γ-Terpinene | 1057 | 1255 | t | 0.4±0.0 | t | t | 0.1±0.0 | 0.2±0.0 | t | 0.8±0.3 | 2.8±0.2 | 0.1±0.0 | 0.4±0.0 | 0.1±0.0 | 1, 2, 3 |
| *cis*-Sabinene hydrate | 1063 | 1556 | --- | --- | --- | --- | --- | --- | 0.3±0.0 | --- | 0.2±0.0 | 0.1±0.0 | --- | --- | 1, 2, 3 |
| *cis*-Linalol oxide | 1065 | 1450 | --- | --- | --- | --- | --- | --- | 0.4±0.1 | --- | --- | --- | --- | --- | 1, 2, 3 |
| Fenchone | 1067 | 1392 | 0.2±0.0 | --- | 0.4±0.1 | --- | 14.2±0.4 | --- | --- | --- | --- | --- | --- | --- | 1, 2 |
| Terpinolene | 1086 | 1265 | t | 0.1±0.0 | 0.1±0.1 | t | t | 0.2±0.0 | t | 0.2±0.1 | 0.1±0.0 | t | 0.7±0.1 | t | 1, 2 |
| Linalol | 1097 | 1553 | 0.4±0.1 | 0.7±0.1 | 0.7±0.0 | 0.5±0.1 | t | 1.0±0.1 | 23.1±0.2 | 9.8±0.7 | 0.7±0.3 | 1.1±0.06 | 0.4±0.1 | 0.1±0.0 | 1, 2, 3 |
| *endo*-Fenchol | 1098 | 1120 | --- | --- | 0.2±0.0 | --- | --- | --- | --- | --- | --- | --- | --- | --- | 1, 2 |
| *cis*-Thujone | 1105 | 1430 | --- | t | --- | --- | --- | 0.1±0.0 | t | --- | t | --- | t | --- | 1, 2, 3 |
| *trans*-Thujone | 1115 | 1449 | --- | --- | --- | 0.1±0.0 | t | --- | --- | t | --- | 37.9±0.1 | --- | --- | 1, 2, 3 |
| *trans*-Pinocarveol | 1138 | 1654 | --- | --- | t | t | t | 0.1±0.0 | t | 0.1±0.0 | t | 0.2±0.0 | t | t | 1, 2 |
| (-)-Citronellal | 1143 | 1491 | --- | 39.6±0.4 | --- | --- | --- | --- | --- | --- | --- | 0.2±0.0 | 0.5±0.1 | --- | 1, 2, 3 |
| *iso*-Borneol | 1144 | 1633 | --- | 0.5±0.0 | --- | --- | --- | --- | --- | 0.1±0.0 | --- | --- | 0.1±0.0 | --- | 1, 2, 3 |
| Camphor | 1145 | 1532 | --- | 1.1±0.0 | 0.6±0.0 | t | t | --- | 0.9±0.0 | 0.2±0.0 | t | 13.9±0.7 | t | --- | 1, 2, 3 |
| Menthofuran | 1150 | 1502 | --- | --- | --- | --- | --- | 0.3±0.0 | --- | --- | --- | --- | --- | --- | 1, 2, 3 |
| *iso*-Pinocamphone | 1153 | 1566 | --- | t | 35.1±0.0 | t | t | 29.1±0.0 | 0.1±0.0 | 0.2±0.0 | 0.1±0.0 | 0.1±0.0 | t | 0.2±0.0 | 1, 2 |
| *trans*-Pinocamphone | 1159 | 1160 | --- | 0.4±0.0 | t | 4.3±0.9 | --- | 11.2±0.9 | --- | t | t | 0.3±0.0 | t | t | 1, 2 |
| Lavandulol | 1162 | 1674 | --- | --- | --- | --- | --- | 4.4±0.4 | --- | --- | --- | --- | --- | --- | 1, 2 |

**(Table 1) Contd….**

| Compound | Ki[a] | Ki[b] | *P. anisum*[c] % | *M. offcinalis* % | *O. basilicum* % | *C. carvi* % | *F. vulgare* % | *H. offcinalis* % | *L. angusti-folia* % | *M. hortensis* % | *O. vulgare* % | *S. officinalis* % | *T. vulgaris* % | *V. officinalis* % | Identifi-cation[d] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *iso*-Menthone | 1163 | 1503 | --- | 8.8±0.9 | --- | --- | --- | --- | --- | --- | --- | --- | 0.1±0.0 | --- | 1, 2, 3 |
| Pinocarvone | 1165 | 1587 | --- | t | 0.4±0.0 | --- | --- | 0.5±0.0 | t | t | t | t | t | t | 1, 2 |
| Borneol | 1167 | 1719 | --- | 0.1±0.0 | 0.2±0.0 | --- | --- | 0.1±0.0 | 6.3±0.9 | 2.0±0.5 | 0.3±0.0 | 7.6±0.4 | 0.2±0.0 | 0.1±0.0 | 1, 2, 3 |
| Terpinen-4-ol | 1176 | 1611 | --- | 0.1±0.0 | 0.2±0.0 | t | t | 0.3±0.1 | 0.2±0.0 | 0.4±0.1 | 0.4±0.0 | 0.5±0.0 | t | 0.2±0.0 | 1, 2, 3 |
| dihydro-Carveol | 1177 | 1755 | --- | --- | --- | --- | 0.3±0.1 | 1.2±0.1 | 0.4±0.0 | 0.8±0.1 | --- | 0.2±0.0 | 0.2±0.0 | --- | 1, 2 |
| *p*-Cymen-8-ol | 1185 | 1864 | --- | t | --- | --- | t | t | 0.3±0.0 | 0.1±0.0 | 0.2±0.0 | 0.1±0.0 | t | t | 1, 2 |
| α-Terpineol | 1189 | 1706 | t | 0.1±0.0 | 1.3±0.3 | t | --- | 1.2±0.1 | 0.4±0.0 | 0.7±0.1 | t | 0.3±0.0 | 0.3±0.0 | 0.3±0.1 | 1, 2, 3 |
| Myrtenal | 1193 | 1648 | --- | --- | 1.0±0.0 | 0.1±0.0 | 0.1±0.0 | 1.0±0.3 | 0.4±0.1 | 0.7±0.1 | --- | 0.2±0.0 | 0.3±0.0 | --- | 1, 2 |
| Estragole | 1195 | 1670 | --- | --- | --- | 65.0±0.9 | 0.8±0.1 | 0.4±0.0 | --- | 0.1±0.0 | 0.1±0.0 | t | --- | --- | 1, 2, 3 |
| Myrtenol | 1196 | 1804 | --- | --- | 0.6±0.0 | --- | --- | 1.3±0.5 | 0.4±0.0 | 0.2±0.1 | --- | 0.2±0.0 | 0.3±0.0 | --- | 1, 2 |
| Citronellol | 1213 | 1772 | --- | 6.2±0.3 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 1, 2, 3 |
| cis-Carveol | 1226 | 1878 | --- | --- | 0.1±0.0 | --- | --- | --- | --- | --- | --- | --- | --- | --- | 1, 2 |
| Isobomyl formate | 1228 | 1596 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 45.4±0.9 | 1, 2 |
| Carvone | 1241 | 1752 | --- | --- | 39.7±0.9 | --- | --- | --- | --- | --- | --- | --- | --- | --- | 1, 2, 3 |
| Linalyl acetate | 1248 | 1565 | --- | 2.3±0.3 | 0.4±0.0 | --- | --- | 0.3±0.0 | 44.4±0.7 | 3.3±0.6 | 0.1±0.0 | 1.5±0.2 | --- | --- | 1, 2, 3 |
| Geraniol | 1255 | 1857 | --- | 5.7±0.3 | --- | --- | --- | --- | 9.3±0.3 | 0.6±0.1 | --- | 0.3±0.0 | --- | --- | 1, 2 |
| cis-Anethole | 1262 | 1780 | 97.1±0.4 | --- | --- | t | 76.3±0.9 | 0.3±0.0 | --- | --- | --- | --- | --- | 0.2±0.0 | 1, 2 |
| (E)-Citral | 1270 | 1727 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 44.5±0.9 | 1, 2, 3 |
| Isobomyl acetate | 1277 | | --- | t | t | 0.1±0.0 | --- | --- | 0.3±0.0 | 0.6±0.1 | t | 0.7±0.0 | t | t | 1, 2 |
| Bornyl acetate | 1284 | 1591 | --- | t | t | 0.1±0.0 | --- | t | 0.2±0.0 | 1.2±0.5 | t | 0.88±0.0 | t | t | 1, 2 |
| Cinnamic acid methyl ester | 1289 | | --- | --- | 0.1±0.0 | --- | --- | --- | --- | --- | --- | --- | --- | --- | 1, 2 |
| Thymol | 1290 | 2198 | --- | 0.1±0.0 | --- | --- | --- | t | --- | 0.7±0.1 | 0.7±0.0 | t | 8.7±0.9 | --- | 1, 2, 3 |
| Carvacrol | 1297 | 2239 | --- | 13.3±0.9 | t | --- | t | t | --- | 4.1±0.9 | 44.0±0.9 | 0.3±0.0 | 24.4±0.9 | --- | 1, 2, 3 |
| Myrtenyl acetate | 1313 | 1698 | --- | --- | 0.5±0.0 | t | --- | 0.6±0.0 | --- | t | t | t | --- | --- | 1, 2 |
| Terpinyl acetate | 1333 | 1709 | --- | --- | --- | --- | --- | --- | --- | 0.5±0.0 | --- | --- | --- | --- | 1, 2 |
| Eugenol | 1353 | 2186 | --- | 0.5±0.0 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 1, 2, 3 |
| Citronellyl acetate | 1358 | 1662 | --- | 1.6±0.9 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 1, 2 |
| Methyl eugenol | 1369 | 2023 | --- | t | 0.5±0.0 | 0.6±0.1 | t | 0.7±0.0 | t | --- | t | --- | --- | t | 1, 2 |
| α-Copaene | 1377 | 1497 | --- | t | 0.1±0.0 | t | t | 0.1±0.0 | t | 0.1±0.0 | 0.1±0.0 | t | t | 0.2±0.1 | 1, 2 |
| Geranyl acetate | 1379 | 1765 | --- | 1.7±0.3 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 1, 2 |
| Isoledene | 1382 | 1367 | --- | t | 0.1±0.0 | t | t | 0.1±0.0 | t | t | 0.1±0.0 | t | t | 0.1±0.0 | 1, 2 |
| β-Bourbonene | 1385 | 1535 | --- | --- | 1.2±0.3 | --- | --- | 1.3±0.3 | --- | --- | --- | --- | --- | --- | 1, 2 |
| β-Elemene | 1387 | 1600 | --- | 0.6±0.0 | 0.1±0.0 | 0.2±0.0 | t | t | --- | t | t | --- | t | 0.2±0.1 | 1, 2 |
| α-Gurjunene | 1408 | 1529 | --- | 0.4±0.0 | 0.4±0.0 | --- | --- | 0.5±0.0 | --- | --- | --- | --- | --- | --- | 1, 2 |
| Longifolene | 1411 | 1576 | --- | 0.9±0.1 | 0.5±0.0 | --- | t | 0.5±0.0 | t | 0.1±0.0 | t | t | t | t | 1, 2 |
| β-Caryophyllene | 1418 | 1612 | t | 0.6±0.0 | 1.4±0.5 | 0.1±0.0 | t | 1.0±0.5 | 1.0±0.9 | 0.3±0.1 | 0.2±0.1 | 1.3±0.0 | 0.1±0.0 | 0.1±0.1 | 1, 2 |
| β-Cedrene | 1424 | 1638 | --- | 0.3±0.0 | 0.5±0.0 | --- | --- | 0.6±0.0 | 1.3±0.1 | 0.5±0.1 | 0.6±0.0 | 1.0±0.0 | --- | 0.4±0.1 | 1, 2 |
| Aromadendrene | 1437 | 1628 | t | t | t | 0.2±0.0 | t | t | t | t | t | 0.1±0.0 | t | --- | 1, 2 |
| α-Humulene | 1455 | 1689 | --- | 0.2±0.0 | 0.5±0.0 | t | t | 0.6±0.0 | 0.6±0.0 | 0.3±0.1 | 0.1±0.0 | 5.9±0.9 | t | 0.2±0.0 | 1, 2 |

**(Table 1) Contd….**

| Compound | Ki[a] | Ki[b] | *P. anisum*[c] % | *M. offcinalis* % | *O. basilicum* % | *C. carvi* % | *F. vulgare* % | *H. offcinalis* % | *L. angustifo-* % | *M. hortensis* % | *O. vulgare* % | *S. offici-nalis* % | *T. vulgaris* % | *V. officinalis* % | Identifi-cation[d] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| allo-Aroma-dendrene | 1463 | 1661 | --- | t | 1.2±0.5 | t | t | 1.4±0.2 | 0.5±0.0 | t | t | 0.1±0.0 | t | 0.1±0.0 | 1, 2 |
| Neryl isobutyrate | 1468 | 1870 | --- | --- | --- | --- | --- | --- | 0.1±0.0 | --- | --- | --- | --- | --- | 1, 2 |
| γ-Gurjunene | 1473 | 1687 | --- | 0.2±0.0 | 0.5±0.0 | --- | t | 0.1±0.0 | --- | 0.1±0.0 | 0.1±0.0 | 0.1±0.0 | t | t | 1, 2 |
| cis-β-Guaiene | 1490 | 1694 | --- | 0.1±0.0 | --- | 0.4±0.2 | --- | 0.4±0.0 | --- | --- | --- | --- | --- | --- | 1, 2 |
| Bicyclogermacrene | 1491 | 1756 | --- | --- | 1.5±0.0 | t | --- | 3.1±0.5 | --- | 0.1±0.0 | --- | --- | --- | 0.1±0.0 | 1, 2 |
| cis-Muurola-4(14),5-diene | 1510 | 1675 | --- | 2.3±0.5 | 3.0±0.9 | 0.1±0.0 | t | 3.7±0.9 | 0.3±0.0 | 0.1±0.0 | t | t | t | 0.2±0.1 | 1, 2 |
| α-7-epi-Selinene | 1518 | 1740 | --- | 0.6±0.0 | 0.1±0.0 | t | t | 0.1±0.0 | --- | 0.1±0.0 | 0.1±0.0 | 0.1±0.0 | t | 0.2±0.1 | 1, 2 |
| Caryophyllene oxide | 1580 | 2008 | --- | 0.2±0.0 | --- | --- | --- | --- | 0.4±0.0 | --- | 0.2±0.0 | 0.8±0.0 | --- | --- | 1, 2 |
| α-Cadinol | 1652 | 2255 | --- | 0.2±0.0 | --- | 0.6±0.1 | --- | 0.3±0.0 | --- | --- | --- | --- | --- | --- | 1, 2 |
| **Total** | | | **98.3** | **96.3** | **97.3** | **98** | **97.8** | **96.4** | **97.0** | **97** | **96.9** | **98.7** | **97.5** | **97.6** | |

The analyses were carried out in triplicate; [a]: Kovats retention index on HP-5 MS column; [b]: Kovats retention index on HP Innowax; [c] --- = absent; t = trace, less than 0.05%; [d]: Identification based on: 1 = Kovats retention index, 2 = mass spectrum, 3 = coinjection with authentic compound.

**Table 2. Effects of Different Doses of Essential Oils of *Hyssopus officinalis*, *Lavandula angustifolia*, *Majorana hortensis*, *Melissa officinalis*, *Ocimum basilicum*, *Origanum vulgare*, *Salvia officinalis*, *Thymus vulgaris*, *Carum carvi*, *Foeniculum vulgare*, *Pimpinella anisum*, *Verbena officinalis* on Germination of *Raphanus sativus* and *Lepidium sativum*. The Data are Expressed as Mean of Three Replicates ± SD**

| ***Raphanus sativus*** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Germinated Seeds** | | | | | | | | | | | | |
| | *P. anisum* | *M. offcinalis* | *O. basilicum* | *C. carvi* | *F. vulgare* | *H. offcinalis* | *L. angustifo-lia* | *M. hortensis* | *O. vulgare* | *S. officinalis* | *T. vulgaris* | *V. officinalis* |
| **Control** | 9.1±1.1 | 9.1±1.1 | 9.1±1.1 | 9.1±1.1 | 9.1±1.1 | 9.1±1.1 | 9.1±1.1 | 9.1±1.1 | 9.1±1.1 | 9.1±1.1 | 9.1±1.1 | 9.1±1.1 |
| **0.06 (µg/mL)** | 9.3±0.6 | 7.7±2.1 | 8.7±1.5 | 2.7±2.1*** | 8.7±1.2 | 6.0±0.0*** | 8.7±1.5 | 8.3±0.6 | 8.3±0.6 | 6.0±2.6** | 8.0±1.0 | 0.7±1.2*** |
| **0.125 (µg/mL)** | 8.7±0.6 | 7.7±0.6 | 9.3±1.2 | 0.0±0.0*** | 8.3±0.6 | 2.3±0.6*** | 6.0±1.7** | 8.7±0.6 | 1.0±1.0*** | 6.7±1.5** | 6.7±1.2** | 0.0±0.0*** |
| **0.25 (µg/mL)** | 9.0±0.0 | 2.0±1.0*** | 8.0±1.0 | 3.3±5.8** | 7.3±1.2* | 0.0±0.6*** | 5.0±0.0*** | 6.3±2.3** | 0.0±0.0*** | 4.7±1.2*** | 1.3±1.2*** | 0.0±0.0*** |
| **0.625 (µg/mL)** | 8.7±0.6 | 0.0±0.0*** | 8.3±1.2 | 0.0±0.0*** | 7.0±1.0** | 0.7±1.2*** | 0.0±0.0*** | 5.7±1.5*** | 0.0±0.0*** | 2.0±2.0*** | 0.0±0.0*** | 0.0±0.0*** |
| **1.25 (µg/mL)** | 9.0±1.0 | 0.0±0.0*** | 8.0±1.7 | 0.0±0.0*** | 5.7±2.3** | 0.0±0.0*** | 0.0±0.0*** | 3.3±2.3*** | 0.0±0.0*** | 0.7±0.6*** | 0.0±0.0*** | 0.0±0.0*** |
| **2.5 (µg/mL)** | 8.0±1.7 | 0.0±0.0*** | 5.7±2.5** | 0.0±0.0*** | 5.0±2.0*** | 0.0±0.0*** | 0.0±0.0*** | 0.0±0.0*** | 0.0±0.0*** | 0.0±0.0*** | 0.0±0.0*** | 0.0±0.0*** |
| ***Lepidium sativum*** | | | | | | | | | | | | |
| **Germinated seeds** | | | | | | | | | | | | |
| | *P. anisum* | *M. offcinalis* | *O. basilicum* | *C. carvi* | *F. vulgare* | *H. offcinalis* | *L. angustifo-lia* | *M. hortensis* | *O. vulgare* | *S. officinalis* | *T. vulgaris* | *V. officinalis* |
| **Control** | 9.3±0.6 | 9.3±0.6 | 9.3±0.6 | 9.3±0.6 | 9.3±0.6 | 9.3±0.6 | 9.3±0.6 | 9.3±0.6 | 9.3±0.6 | 9.3±0.6 | 9.3±0.6 | 9.3±0.6 |
| **0.06 (µg/mL)** | 10.0±0.0 | 9.7±0.6 | 10.0±0.0 | 9.7±0.6 | 9.7±0.6 | 9.3±1.2 | 8.7±0.6 | 9.0±1.0 | 9.3±0.6 | 9.0±1.0 | 9.7±0.6 | 9.3±0.6 |

**(Table 2) Contd….**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Lepidium sativum*** | | | | | | | | | | | | |
| **Germinated seeds** | | | | | | | | | | | | |
| **0.125 (µg/mL)** | 10.0±0.0 | 9.0±0.0 | 9.3±0.6 | 8.3±0.6 | 9.7±0.6 | 9.7±0.6 | 9.3±0.6 | 9.0±1.0 | 8.3±2.1 | 9.0±1.0 | 9.7±0.6 | 8.3±1.2 |
| **0.25 (µg/mL)** | 8.7±0.6 | 9.0±1.7 | 9.7±0.6 | 8.3±1.2 | 9.3±0.6 | 10.0±0.0 | 9.3±0.6 | 8.7±1.2 | 6.3±4.7 | 9.7±0.6 | 7.7±0.6* | 0.0±0.0*** |
| **0.625 (µg/mL)** | 9.7±0.6 | 5.3±1.2*** | 9.7±0.6 | 3.7±2.1* | 9.3±0.6* | 9.3±0.6 | 9.7±0.6 | 10.0±0.0 | 7.3±2.1 | 9.3±0.6 | 4.0±1.7** | 9.0±1.0 |
| **1.25 (µg/mL)** | 8.0±1.0 | 0.3±0.6*** | 8.3±1.2 | 0.7±1.2*** | 9.0±1.0 | 8.7±0.6 | 8.3±1.2 | 8.7±0.6 | 0.0±0.0*** | 8.3±1.5 | 0.0±0.0*** | 8.7±0.6 |
| **2.5 (µg/mL)** | 0.7±1.2*** | 0.0±0.0*** | 3.3±3.5* | 0.0±0.0*** | 4.3±2.3* | 0.0±0.0*** | 1.3±2.3** | 6.3±1.5* | 0.3±0.6*** | 1.3±1.5** | 0.0±0.0*** | 0.0±0.0*** |

The values, followed by * (*p < 0.05; **p < 0.01, ***p < 0.001), are statistically different according to the Student's *t* test.

**Table 3. Effects of Different doses of Essential Oils of *Hyssopus officinalis*, *Lavandula angustifolia*, *Majorana hortensis*, *Melissa officinalis*, *Ocimum basilicum*, *Origanum vulgare*, *Salvia officinalis*, *Thymus vulgaris*, *Carum carvi*, *Foeniculum vulgare*, *Pimpinella anisum*, *Verbena officinalis* on Radicle Elongation of *Raphanus sativus* and *Lepidium sativum*. The Data are Expressed as Mean of Three Replicates ± SD**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Raphanus sativus*** | | | | | | | | | | | | |
| **Radicle Length (cm ± SD)** | | | | | | | | | | | | |
| | *P. anisum* | *M. offcinalis* | *O. basilicum* | *C. carvi* | *F. vulgare* | *H. offcinalis* | *L. angustifolia* | *M. hortensis* | *O. vulgare* | *S. officinalis* | *T. vulgaris* | *V. officinalis* |
| **Control** | 3.0±0.9 | 3.0±0.9 | 3.0±0.9 | 3.0±0.9 | 3.0±0.9 | 3.0±0.9 | 3.0±0.9 | 3.0±0.9 | 3.0±0.9 | 3.0±0.9 | 3.0±0.9 | 3.0±0.9 |
| **0.06 (µg/mL)** | 3.2±0.2 | 2.5±0.3 | 2.9±0.1 | 1.5±0.6* | 2.7±0.8 | 1.6±0.4* | 2.7±0.3 | 2.3±0.4 | 1.6±0.3* | 2.2±0.4 | 1.7±0.7* | 0.2±0.3*** |
| **0.125 (µg/mL)** | 3.1±0.1 | 1.8±0.4 | 2.8±0.6 | 0.0±0.0*** | 2.3±0.3 | 1.4±0.7* | 2.5±0.2 | 2.8±0.3 | 0.5±0.5*** | 2.1±0.3 | 0.8±0.2** | 0.0±0.0*** |
| **0.25 (µg/mL)** | 2.9±0.2 | 0.3±0.2*** | 2.6±0.1 | 0.3±0.6*** | 2.9±1.4 | 0.9±1.3** | 2.3±0.2 | 2.1±0.6 | 0.0±0.0*** | 1.6±0.4* | 0.7±0.6*** | 0.0±0.0*** |
| **0.625 (µg/mL)** | 2.7±0.2 | 0.0±0.0*** | 2.3±0.4 | 0.0±0.0*** | 2.3±0.4 | 0.4±0.7*** | 0.0±0.0*** | 1.7±0.2* | 0.0±0.0*** | 0.9±0.8** | 0.0±0.0*** | 0.0±0.0*** |
| **1.25 (µg/mL)** | 2.0±0.1 | 0.0±0.0*** | 2.7±0.5 | 0.0±0.0*** | 1.9±0.3 | 0.0±0.0*** | 0.0±0.0*** | 1.3±0.4** | 0.0±0.0*** | 0.5±0.5*** | 0.0±0.0*** | 0.0±0.0*** |
| ***Lepidium sativum*** | | | | | | | | | | | | |
| **Radicle length (cm ± SD)** | | | | | | | | | | | | |
| | *P. anisum* | *M. offcinalis* | *O. basilicum* | *C. carvi* | *F. vulgare* | *H. offcinalis* | *L. angustifolia* | *M. hortensis* | *O. vulgare* | *S. officinalis* | *T. vulgaris* | *V. officinalis* |
| **Control** | 6.1±1.3 | 6.1±1.3 | 6.1±1.3 | 6.1±1.3 | 6.1±1.3 | 6.1±1.3 | 6.1±1.3 | 6.1±1.3 | 6.1±1.3 | 6.1±1.3 | 6.1±1.3 | 6.1±1.3 |
| **0.06 (µg/mL)** | 7.6±0.3 | 4.5±0.4 | 3.7±0.5* | 3.4±0.4* | 5.7±0.5 | 5.9±1.3 | 4.5±0.3 | 2.3±0.5* | 3.8±0.9 | 3.9±0.3* | 4.3±0.1 | 3.8±0.4* |
| **0.125 (µg/mL)** | 5.3±0.1 | 4.2±0.5 | 6.1±0.8 | 2.3±0.1** | 6.0±0.5 | 4.6±0.4 | 5.1±0.2 | 1.6±0.3** | 2.6±0.2* | 2.9±0.3* | 3.0±0.4* | 1.9±0.5** |
| **0.25 (µg/mL)** | 3.4±0.6* | 1.0±0.7** | 4.5±0.9 | 1.9±0.3** | 4.9±0.3 | 3.5±0.3* | 2.1±0.4** | 1.4±0.5** | 1.0±0.8** | 2.3±0.4** | 1.1±0.2** | 0.0±0.0** |
| **0.625 (µg/mL)** | 4.4±0.9 | 0.4±0.2** | 5.8±0.7 | 0.3±0.1** | 5.0±0.7 | 3.7±0.4* | 3.7±0.5* | 1.9±0.3** | 0.9±0.3** | 0.9±0.2** | 0.2±0.1** | 2.8±0.4* |
| **1.25 (µg/mL)** | 3.1±0.2* | 0.0±0.1** | 3.4±0.3* | 0.1±0.1** | 3.4±1.1 | 2.8±0.3* | 3.1±0.3* | 0.9±0.3** | 0.0±0.0** | 0.4±0.1** | 0.0±0.0** | 1.1±0.2** |

The values, followed by * (*p < 0.05; **p < 0.01, ***p < 0.001), are statistically different according to the Student's *t* test.

observed directly in Petri dishes, each 24 h. Vaporization assay of essential oils has been surprising: almost all the oils have given proof of total inhibition of germination and radical elongation of two species assayed. Cress has been totally inhibited quite everytime; radish has been inhibited both in germination and in radical growth.

Mancini and coworkers [21] determined the compositions (Table **4**) and the effects against germination and initial radical elongation of radish and garden cress of the essential oils from *Nepeta curviflora* and *Nepeta nuda* ssp. *albiflora*, collected in Lebanon in different sites (Tables **5** and **6**).

Thirty-six components in the essential oil from *N. curviflora* were identified accounting for the 91.3% of the total oil. Sesquiterpene hydrocarbons were the most abundant compounds and represented 61.2% of total oil. The major components of this oil were β-caryophyllene (41.6%), (*E*)-β-farnesene (6.2%) and (*Z*)-β-farnesene (4.8%); caryophyllene oxide (9.5%) was instead the main oxygen containing sesquiterpene. Thirty-six components in the oil from *N. nuda* L. subsp. *albiflora* collected in Laklouk representing 92.8% of the total oil were identified. Also in this case sesquiterpene hydrocarbons (38.4%) prevailed over the other compounds and in this oil, β-bisabolene (11.8%), (*E*)-β-farnesene (7.1%) and β-sesquiphellandrene (4.1%) were the main components. Oxygen containing monoterpenes (27.3%) were also abundant, particularly pulegone (10.8%) and (*E,Z*)-nepetalactone (8.0%). Noteworthy was also the presence of the oxygenated sesquiterpene caryophyllene oxide (6.9%). The oil from the same species collected in Tannourine Cedar Forest presented a different composition. Fifty-two compounds in all were identified accounting for 91.2% of the oil. The amount of sesquiterpene hydrocarbons (22.7%) and oxygenated sesquiterpenes (22.5%) was similar: in the first fraction β-bisabolene (7.8%) prevailed, while in the second one the main compound was caryophyllene oxide (7.3%). The oxygenated monoterpenes pulegone (7.2%) and (*E,Z*)-nepetalactone (4.4%) were also present in a significant percentage. The three essential oils were studied for their phytotoxic activity against germination and initial radical elongation of radish and garden cress: the germination of radish and garden cress appeared no significantly sensitive to three essential oils, while radical elogation was affected at the highest dose tested. Radical elongation of radish was affected significantly by *N. nuda* essential oil, at the highest dose tested. Radical elongation of garden cress seemed significantly less sensitive to *N. curviflora* oil. At the highest dose tested, the essential oil of *N. curviflora* promoted significantly the germination of radish. Radical elongation of garden cress was weakly inhibited in response to 1.25 μg/ml and 0.625 μg/ml of *N. nuda*.

The essential oils also from *S. hierosolymitana* and *S. multicaulis* var. *simplicifolia* (Table **7**) collected in Lebanon were evaluated on germination and initial radical elongation of *Raphanus sativus* L. and *Lepidium sativum* L. (Tables **8** and **9**) [22]. In all, 115 compounds were identified: 82 for S *hierosolymitana* and 72 for *S. multicaulis* var. *simplicifolia*. S. *multicaulis* var. *simplicifolia* oil is rich of monoterpenes (34.5%) and sesquiterpenes (46.9%). In *S. hierosolymitana* the monoterpenoid fraction amounted to 17.7% of the oil and was characterized only by oxygenated monoterpenoids, amongst which the most abundant was α-thujone (3.0%). The sesquiterpenoid fraction was mainly composed of sesquiterpenoid hydrocarbons (11.5%). Noteworthy was the content of carbonylic compounds (17%), amongst which the C-18 ketone hexahydrofarnesyl acetone and the C-13 ketone β-ionone were particularly abundant; other components of the oil were fatty acids (21.4%). In the oil from *S. multicaulis* var. *simplicifolia* the sesquiterpenoid fraction amounted to 46.9% of the total oil, while the monoterpenoid fraction was lower (34.5%). Differently from *S. hierosolymitana*, in which monoterpenoid hydrocarbons were completely absent, in *S. multicaulis* oil they accounted for the 10.6% and were particularly represented by α-pinene (5.5%). Also oxygenated monoterpenoids were abundant (23.9%) and in this fraction the main compounds were myrtenol (4.6%) and sabinyl acetate (4.6%). Among sesquiterpenoids, sesquiterpenoid hydrocarbons (38.6%) prevailed, particularly α-copaene (6.6%), β-caryophyllene (4.4%) and aromadendrene (3.9%). Another important difference in comparison with *S. hierosolymitana* essential oil was the paucity of carbonylic compounds and of fatty acids.

Tables **8** and **9** report the phytotoxic activity of these essential oils against germination and initial radical elongation of radish and garden cress. The oils affected the germination and the radical elongation of radish and garden cress in a different way. Radical elongation seemed to be more affected than germination. The germination of radish did not appear significantly sensitive to the two essential oils. Moreover, at a dose of 0.625 μg/mL the essential oil of *S. hierosolymitana* significantly inhibited the germination of radish. At the lowest dose tested the essential oil of *S. multicaulis* var. *simplicifolia* significantly promoted the germination of radish. The germination of garden cress was weakly inhibited in response to 0.125 μg/mL of essential oil of *S. multicaulis* var. *simplicifolia*. Radical elongation of radish was inhibited significantly in response to 0.125 μg/mL and 1.25 μg/mL of *S. multicaulis* var. *simplicifolia*. Radical elongation of garden cress was promoted in response to 0.625 μg/mL of essential oil of *S. multicaulis* var. *simplicifolia*.

Because of Muller and coworkers based their biological studies on *Salvia* "phenomenon" [8-12], we decided to study other species of the same genus. In a next paper, we studied the chemical composition (Table **10**) and phytotoxic activity (Tables **11** and **12**) of essential oils from other five species of *Salvia* [25]. In *S. africana* the monoterpenes and sesquiterpenes were almost in a similar percentage, amounting to 50.6% and 43.2%, respectively. The main compounds were *p*-cymene (21.2%), γ-terpinene (15.5%), both monoterpenes, τ-cadinol (13.6%) and α-eudesmol (10.7%), oxygenated sesquiterpenes. In the oil from *S. elegans*, the monoterpenes amounted to 68.2% and consisted mainly of oxygenated compounds (62.7%); on the other hand, the total sesquiterpenes were 24.0% (20.9% sesquiterpene hydrocarbons and 3.1% of oxygenated sesquiterpenes) of the total oil. *cis*-Thujone (38.7%) was the most abundant among oxygenated monoterpenes. The main sesquiterpene hydrocarbons was δ-cadinene (11.5%). In the oil from *S. greggii*, the monoterpene fraction amounted to 70.0% of the total oil, while sesquiterpenes accounted for only 24.5%. In the monoterpene fraction, oxygenated monoterpenes represent a great amount, accounting for 68.9%. The main components were

**Table 4. Essential Oil Compositions (%) of *N. curviflora*, *N. nuda* L. subsp. *albiflora* Collected in Laklouk (L) and *N. nuda* L. subsp. *albiflora* Collected in Tannourine Cedar Forest (T)**

| Compound | Ki [a] | Ki [b] | *N. curviflora* [c] % | *N. nuda* L % | *N. nuda* T % | Identification [d] |
|---|---|---|---|---|---|---|
| 1,8-cineole | 1034 | 1213 | 0.1 | 2.1 | --- | 1, 2, 3 |
| Linalool | 1098 | 1553 | 2.2 | --- | 1.2 | 1, 2, 3 |
| *p*-Methylguaiacol | 1165 | | t | --- | --- | 1, 2 |
| α-Terpineol | 1189 | 1706 | 0.8 | t | --- | 1, 2, 3 |
| Pulegone | 1233 | 1665 | --- | 10.8 | 7.2 | 1, 2 |
| Dihydroedulan II | 1285 | | --- | 1.2 | --- | 1, 2 |
| Piperitone | 1343 | | --- | 2.3 | 1.0 | 1, 2 |
| (*Z*,*Z*)-Nepetalactone | 1368 | | --- | 0.5 | 2.9 | 1, 2 |
| α-Copaene | 1377 | 1497 | 0.1 | 1.4 | 0.6 | 1, 2 |
| (*E*)-β-Damascenone | 1380 | 1838 | 0.5 | 1.0 | --- | 1, 2 |
| (*Z*,*E*)-Nepetalactone | 1382 | | 5.7 | 3.6 | 0.8 | 1, 2 |
| β-Cubebene | 1382 | 1547 | --- | 0.7 | --- | 1, 2 |
| β-Bourbonene | 1385 | 1535 | 1.0 | 2.5 | 0.9 | 1, 2 |
| (*E*,*Z*)-Nepetalactone | 1407 | | --- | 8.0 | 4.4 | 1, 2 |
| β-Caryophyllene | 1418 | 1612 | 41.6 | 1.6 | 2.5 | 1, 2, 3 |
| γ-Elemene | 1418 | 1650 | t | --- | --- | 1, 2 |
| Aromadendrene | 1437 | 1628 | 1.6 | 1.2 | 0.8 | 1, 2 |
| (*Z*)-β-Farnesene | 1439 | | 4.8 | --- | --- | 1, 2 |
| α-Humulene | 1455 | 1689 | 1.3 | --- | 1.0 | 1, 2 |
| (*E*)-β-Farnesene | 1457 | 1673 | 6.2 | 7.1 | 1.9 | 1, 2 |
| *allo*-Aromadendrene | 1463 | 1661 | 0.5 | --- | --- | 1, 2 |
| γ-Gurjunene (5,11-Guaiadiene) | 1473 | | --- | --- | 0.6 | 1, 2 |
| β-Selinene | 1474 | 1715 | 0.1 | --- | --- | 1, 2 |
| Germacrene D | 1477 | 1726 | 0.7 | --- | 0.6 | 1, 2 |
| γ-Muurolene | 1478 | 1704 | --- | 2.7 | 0.5 | 1, 2 |
| *ar*-Curcumene | 1483 | 1784 | --- | --- | 1.7 | 1, 2 |
| Epizonarene | 1485 | | --- | --- | 0.5 | 1, 2 |
| Bicyclosesquiphellandrene | 1488 | 1626 | --- | 1.3 | --- | 1, 2 |
| α-Muurolene | 1500 | 1740 | --- | 1.3 | 0.7 | 1, 2 |
| β-Bisabolene | 1510 | 1743 | 1.3 | 11.8 | 7.8 | 1, 2 |
| γ-Cadinene | 1515 | 1776 | --- | 0.3 | 1.2 | 1, 2 |
| 1-*endo*-Bourbonanol | 1520 | | t | --- | 0.4 | 1, 2 |
| δ-Cadinene | 1526 | 1773 | 1.5 | 2.4 | --- | 1, 2 |
| β-Sesquiphellandrene | 1532 | | --- | 4.1 | --- | 1, 2 |
| α-Calacorene | 1541 | 1941 | --- | --- | 0.4 | 1, 2 |
| α-Cadinene | 1543 | 1745 | 0.5 | --- | 1.0 | 1, 2 |

**(Table 4) Contd….**

| Compound | Ki[a] | Ki[b] | *N. curviflora*[c] % | *N. nuda* L % | *N. nuda* T % | Identification[d] |
|---|---|---|---|---|---|---|
| 11-Norbourbonan-1-one | 1559 | | 0.2 | --- | --- | 1, 2 |
| Ledol | 1565 | 2057 | --- | --- | 0.6 | 1, 2 |
| Palustrol | 1567 | | --- | --- | 0.3 | 1, 2 |
| (*Z*)-3-Hexenyl benzoate | 1570 | | 0.5 | --- | --- | 1, 2 |
| Germacrene D 4-ol | 1577 | 2069 | 0.1 | --- | --- | 1, 2 |
| Spathulenol | 1578 | 2150 | 3.9 | 2.7 | 1.9 | 1, 2 |
| Isocaryophyllene oxide | 1579 | | --- | --- | 0.5 | 1, 2 |
| Caryophyllene oxide | 1580 | 2008 | 9.5 | 6.9 | 7.3 | 1, 2, 3 |
| Globulol | 1589 | 2098 | 0.2 | --- | --- | 1, 2 |
| Guaiol | 1598 | 2108 | --- | 1.0 | --- | 1, 2 |
| Widdrol | 1600 | | --- | 1.9 | 1.4 | 1, 2 |
| (E)-Sesquilavandulol | 1601 | | --- | --- | 1.9 | 1, 2 |
| α-Cedrol | 1602 | | --- | --- | 0.7 | 1, 2 |
| Humulene epoxide II | 1605 | 2011 | t | 1.0 | --- | 1, 2 |
| *nor*-Copaanone | 1622 | | --- | --- | 0.2 | 1, 2 |
| Caryophylladienol I | 1640 | | --- | --- | 1.0 | 1, 2 |
| t-Cadinol | 1640 | 2187 | --- | --- | 1.9 | 1, 2 |
| t-Muurolol | 1642 | 2209 | --- | --- | 1.8 | 1, 2 |
| Torreyol | 1645 | 2145 | --- | --- | 1.0 | 1, 2 |
| α-Cadinol | 1652 | 2255 | 0.3 | 1.2 | --- | 1, 2 |
| *cis*-14-muurol-5-en-4-one | 1667 | | --- | --- | --- | 1, 2 |
| Longifolol | 1717 | | --- | --- | 1.5 | 1, 2 |
| 14-Hydroxy-α-humulene | 1718 | 2478 | --- | 0.9 | --- | 1, 2 |
| Tetradecanoic acid | 1758 | 2672 | --- | --- | 0.9 | 1, 2, 3 |
| (*Z*)-Lanceol | 1765 | | t | --- | 0.1 | 1, 2 |
| Hexahydrofarnesylacetone | 1845 | 2131 | 1.6 | 2.0 | 1.9 | 1, 2 |
| Neophytadiene | 1845 | | --- | --- | 0.3 | 1, 2 |
| Hexadecanoic acid methyl ester | 1925 | | 0.6 | --- | --- | 1, 2, 3 |
| (*Z*)-Phytol | 1949 | | 1.3 | --- | 0.6 | 1, 2 |
| Hexadecanoic acid | 1957 | 2931 | --- | 1.7 | 10.1 | 1, 2, 3 |
| Heneicosane | 2100 | | --- | t | --- | 1, 2, 3 |
| (*Z*,*Z*)-Octadecadienoic acid | 2122 | | 0.2 | --- | --- | 1, 2, 3 |
| Docosane | 2200 | | --- | --- | 0.5 | 1, 2, 3 |
| Tricosane | 2300 | | 1.1 | 0.5 | 1.4 | 1, 2, 3 |
| Tetracosane | 2400 | 2400 | --- | --- | 0.4 | 1, 2, 3 |
| Pentacosane | 2500 | 2500 | 1.3 | 1.5 | 4.0 | 1, 2, 3 |
| Hexacosane | 2600 | 2600 | --- | --- | 1.1 | 1, 2, 3 |

**(Table 4) Contd….**

| Compound | Ki[a] | Ki[b] | *N. curviflora*[c] % | *N. nuda* L % | *N. nuda* T % | Identification[d] |
|---|---|---|---|---|---|---|
| Heptacosane | 2700 | 2700 | --- | 0.3 | 2.8 | 1, 2, 3 |
| Octacosane | 2800 | 2800 | --- | --- | 0.3 | 1, 2, 3 |
| Nonacosane | 2900 | 2900 | --- | --- | 1.2 | 1, 2 |
| Hentriacontane | 3100 | 3100 | --- | 0.6 | 1.0 | 1, 2 |
| **Total** | | | **91.3** | **90.1** | **91.2** | |

The analyses were carried out in triplicate; [a]: Kovats retention index on HP-5 MS column; [b]: Kovats retention index on HP Innowax; [c] --- = absent; t = trace, less than 0.05%; [d]: Identification based on: 1 = Kovats retention index, 2 = mass spectrum, 3 = coinjection with authentic compound.

**Table 5. Effects of Different Doses of Essential Oils of *N. curviflora*, *N. nuda* L. subsp. *albiflora* Collected in Laklouk (L) and *N. nuda* L. subsp. *albiflora* Collected in Tannourine Cedar Forest (T) on Germination of *Raphanus sativus* and *Lepidium sativum*. The Data are Expressed as Mean of Three Replicates ± SD**

| ***Raphanus sativus*** | | | |
|---|---|---|---|
| **Germinated Seeds** | | | |
| | ***Nepeta nuda (T)*** | ***Nepeta curviflora*** | ***Nepeta nuda (L)*** |
| **Negative control** | 13.0 ± 0.0 | 10.0 ± 0.0 | 10.0 ± 0.0 |
| **Control** | 14.3 ± 0.6 | 11.7 ± 2.1 | 11.7 ± 2.1 |
| **0.250 (µg/mL)** | 12.7 ± 1.5 | 12.3 ± 1.5 | 11.7 ± 2.9 |
| **0.625 (µg/mL)** | 13.3 ± 2.1 | 11.7 ± 0.6 | 12.0 ± 1.7 |
| **1.25 (µg/mL)** | 13.3 ± 0.6 | 10.7 ± 3.5 | 13.0 ± 1.0 |
| **2.50 (µg/mL)** | 12.0 ± 1.7 | 12.3 ± 0.6 | 12.3 ± 2.1 |
| ***Lepidium sativum*** | | | |
| **Germinated Seeds** | | | |
| | ***Nepeta nuda (T)*** | ***Nepeta curviflora*** | ***Nepeta nuda (L)*** |
| **Negative control** | 13.0 ± 0.0 | 13.0 ± 1.7 | 13.0 ± 1.7 |
| **Control** | 13.7 ± 1.7 | 13.7 ± 1.7 | 13.7 ± 1.2 |
| **0.250 (µg/mL)** | 12.7 ± 1.5 | 12.3 ± 1.5 | 13.0 ± 0.0 |
| **0.625 (µg/mL)** | 12.7 ± 0.6* | 13.3 ± 2.1 | 11.0 ± 1.7 |
| **1.25 (µg/mL)** | 13.7 ± 0.6 | 13.3 ± 0.6 | 12.0 ± 3.0 |
| **2.50 (µg/mL)** | 12.3 ± 1.2 | 13.7 ± 0.6 | 10.7 ± 0.6* |

The values, followed by * (*p < 0.05; **p < 0.01, ***p < 0.001), are statistically different according to the Student's *t* test.

*cis*-thujone (43.4%) and geranyl acetate (8.7%). δ-Cadinene (14.0%) was the most abundant sesquiterpene hydrocarbon. In the *S. mellifera* oil, the monoterpene fraction amounted to 76.1%, while the sesquiterpene one was 14.2%. Also in this case, the monoterpene fraction was mainly represented by oxygenated compounds (57.0%), with great prevalence of 1,8-cineole (39.8%) and camphor (12.2%). α-Pinene (9.2%) was the major component of non-oxygenated monoterpenes. In *S. munzii*, the monoterpene fraction amounted to 80.3% of the total oil, while sesquiterpenes represented only 15.6%: the main compounds are *cis* thujone (33.3%) and camphor (27.2%). The five essential oils were evaluated for their phytotoxic activity against germination (Table **11**) and initial radical elongation (Table **12**) of radish and garden cress. The oils affected the germination and the radical elongation of two seeds in a distinct way. The germination of radish appeared sensitive to *Salvia greggii* oil, at the highest dose (1.25 µg/mL) used. The germination of garden cress was completely inhibited by *S. elegans*, *S. greggii* and *S. munzii* oils, at the highest doses (1.25 µg/mL, 0.625 µg/mL) used. The essential oil of *S. elegans*, at the almost all doses tested, inhibited significantly the radical elongation of both radish and garden cress. Also *S. greggii* and *S. munzii* oils inhibited, in a significative way, the radical elongation as of radish as of garden cress; on the other hand, *S. mellifera* oil inhibited, in a significative way, the radical elongation of radish but

**Table 6. Effects of Different Doses of Essential Oils of *N. curviflora*, *N. nuda* L. subsp. *albiflora* Collected in Laklouk (L) and *N. nuda* L. subsp. *albiflora* Collected in Tannourine Cedar Forest (T) on Radical Elongation of *Raphanus sativus* and *Lepidium sativum*. The Data are Expressed as Mean of three Replicates ± SD**

| ***Raphanus sativus*** | | | |
|---|---|---|---|
| **Radicle length (cm ± SD)** | | | |
| | ***Nepeta nuda* (T)** | ***Nepeta curviflora*** | ***Nepeta nuda* (L)** |
| **Negative control** | 3.2 ± 1.5 | 1.4 ± 0.8 | 1.4 ± 0.8 |
| **Control** | 3.0 ± 1.1 | 2.0 ± 1.3 | 2.0 ± 1.3 |
| **0.250 (µg/mL)** | 2.0 ± 1.3*** | 1.7 ± 1.1 | 2.0 ± 1.6 |
| **0.625 (µg/mL)** | 2.3 ± 1.2** | 1.5 ± 1.3 | 1.9 ± 1.0 |
| **1.25 (µg/mL)** | 1.6 ± 1.1*** | 1.4 ± 1.4 | 1.8 ± 1.1 |
| **2.50 (µg/mL)** | 1.9 ± 1.3*** | 1.6 ± 0.9 | 1.7 ± 1.3 |
| ***Lepidium sativum*** | | | |
| **Radicle length (cm ± SD)** | | | |
| | ***Nepeta nuda* (T)** | ***Nepeta curviflora*** | ***Nepeta nuda* (L)** |
| **Negative control** | 3.2 ± 1.5 | 3.3 ± 1.5 | 3.3 ± 1.5 |
| **Control** | 3.0 ± 1.1 | 2.6 ± 1.4 | 2.6 ± 1.4 |
| **0.250 (µg/mL)** | 2.6 ± 1.3 | 2.6 ± 1.3 | 2.2 ± 1.4 |
| **0.625 (µg/mL)** | 3.2 ± 1.5 | 2.7 ± 1.8 | 2.0 ± 1.0* |
| **1.25 (µg/mL)** | 3.2 ± 1.2 | 2.4 ± 1.3 | 2.0 ± 1.3 |
| **2.50 (µg/mL)** | 3.4 ± 1.2 | 2.9 ± 1.7 | 2.3 ± 1.3 |

The values, followed by * (*p < 0.05; **p < 0.01, ***p < 0.001), are statistically different according to the Student's *t* test.

**Table 7. Essential oil Compositions (%) of *Salvia hierosolymitana* and *Salvia multicaulis* var. *simplicifolia***

| Compound | Ki[a] | Ki[b] | *S. hierosolymitana*[c] % | *S. multicaulis* var. *simplicifolia* % | Identification[d] |
|---|---|---|---|---|---|
| (*Z*)-4-Heptenal | 901 | 1238 | t | --- | 1, 2 |
| α-Pinene | 938 | 1032 | --- | 5.5 | 1, 2, 3 |
| Camphene | 953 | 1076 | --- | 0.9 | 1, 2, 3 |
| Benzaldehyde | 963 | 1543 | 0.7 | --- | 1, 2, 3 |
| Sabinene | 973 | 1132 | --- | 0.4 | 1, 2 |
| 1-Octen-3-one | 975 | 1312 | 0.1 | --- | 1, 2 |
| β-Pinene | 980 | 1118 | --- | 0.9 | 1, 2, 3 |
| Myrcene | 993 | 1174 | --- | 0.3 | 1, 2 |
| 2-Pentylfuran | 1002 | 1243 | t | --- | 1, 2 |
| (*E*,*E*)-2,4-Heptadienal | 1015 | 1507 | 0.2 | --- | 1, 2 |
| *p*-Cymene | 1025 | 1280 | --- | 2.3 | 1, 2 |
| Limonene | 1030 | 1203 | --- | 0.3 | 1, 2, 3 |
| 1,8-Cineole | 1034 | 1213 | 0.8 | 3.1 | 1, 2, 3 |
| Phenylacetaldehyde | 1048 | 1663 | 1.0 | --- | 1, 2, 3 |
| (*E*)-2-Octenal | 1055 | 1466 | 0.5 | --- | 1, 2 |

**(Table 7) Contd.…**

| Compound | Ki[a] | Ki[b] | *S. hierosolymitana*[c] % | *S. multicaulis* var. *simplicifolia* % | Identification[d] |
|---|---|---|---|---|---|
| *cis*-Linalool oxide (furanoid) | 1074 | 1482 | 0.4 | --- | 1, 2 |
| *trans*-Linalool oxide (furanoid) | 1085 | 1455 | 0.6 | --- | 1, 2 |
| Linalool | 1098 | 1553 | 1.9 | 0.5 | 1, 2, 3 |
| α-Thujone | 1105 | 1430 | 3.0 | 1.0 | 1, 2 |
| β-Thujone | 1115 | 1451 | 1.6 | 0.9 | 1, 2 |
| *trans*-Pinocarveol | 1137 | 1664 | --- | 0.6 | 1, 2 |
| Camphor | 1145 | 1532 | 0.9 | 0.8 | 1, 2, 3 |
| (*E*,*Z*)-2,6-Nonadienal | 1154 | 1572 | t | --- | 1, 2 |
| Borneol | 1167 | 1719 | --- | 1.2 | 1, 2, 3 |
| Terpinen-4-ol | 1176 | 1611 | 0.5 | 1.2 | 1, 2, 3 |
| Naphtalene | 1179 | 1763 | 0.3 | --- | 1, 2, 3 |
| *p*-Methylacetophenone | 1184 | 1797 | 0.5 | --- | 1, 2 |
| α-Terpineol | 1189 | 1706 | 1.1 | --- | 1, 2 |
| Myrtenal | 1193 | 1648 | 0.7 | 1.8 | 1, 2 |
| Myrtenol | 1196 | 1804 | 0.6 | 4.6 | 1, 2 |
| Safranal | 1197 | 1597 | 0.4 | --- | 1, 2 |
| Decanal | 1206 | 1510 | t | --- | 1, 2 |
| α-Ionene | 1208 | 1567 | 0.3 | --- | 1, 2 |
| *trans*-Carveol | 1217 | 1845 | --- | 0.2 | 1, 2 |
| Myrtenyl acetate | 1227 | 1698 | --- | 1.8 | 1, 2 |
| Geraniol | 1235 | 1857 | 0.2 | --- | 1, 2 |
| Pulegone | 1237 | 1665 | 1.4 | --- | 1, 2 |
| Neral | 1240 | 1656 | 0.9 | --- | 1, 2 |
| Linalyl acetate | 1259 | 1665 | 1.6 | --- | 1, 2, 3 |
| Bornyl acetate | 1284 | 1597 | --- | 0.5 | 1, 2, 3 |
| Indole | 1290 | 2471 | 0.7 | --- | 1, 2, 3 |
| Thymol | 1293 | 2198 | --- | 1.7 | 1, 2, 3 |
| Sabinyl acetate | 1295 | 1658 | 0.6 | 4.6 | 1, 2 |
| Carvacrol | 1299 | 2239 | --- | 0.6 | 1, 2, 3 |
| 4-Vinylguaiacol | 1312 | 2180 | 4.0 | --- | 1, 2 |
| α-Terpinyl acetate | 1333 | 1709 | --- | 0.5 | 1, 2 |
| Piperitenone | 1343 | 1948 | 0.5 | 0.6 | 1, 2 |
| α-Cubebene | 1352 | 1466 | --- | 0.3 | 1,2 |
| Eugenol | 1353 | 2186 | --- | 1.5 | 1, 2, 3 |
| Cyclosativene | 1363 | 1492 | 0.5 | --- | 1, 2 |
| Ylangene | 1372 | 1493 | --- | 0.3 | 1, 2 |

**(Table 7) Contd….**

| Compound | Ki[a] | Ki[b] | *S. hierosolymitana*[c] % | *S. multicaulis* var. *simplicifolia* % | Identification[d] |
|---|---|---|---|---|---|
| α-Copaene | 1377 | 1497 | 1.7 | 6.6 | 1, 2 |
| (*E*)-β-Damascenone | 1382 | 1838 | 2.2 | 0.2 | 1, 2 |
| β-Bourbonene | 1385 | 1535 | 0.6 | 0.7 | 1, 2 |
| β-Elemene | 1387 | 1600 | --- | 0.8 | 1, 2 |
| α-Cedrene | 1411 | 1568 | 0.5 | --- | 1, 2 |
| β-Caryophyllene | 1415 | 1612 | 2.4 | 4.4 | 1, 2, 3 |
| Aromadendrene | 1437 | 1628 | --- | 3.9 | 1, 2 |
| (*E*)-β-Farnesene | 1452 | 1673 | 1.2 | 1.2 | 1, 2 |
| (*E*)-Geranyl acetone | 1454 | 1854 | 0.8 | --- | 1, 2 |
| α-Humulene | 1455 | 1689 | 0.9 | 0.5 | 1, 2 |
| *allo*-Aromadendrene | 1463 | 1661 | 0.4 | 1.1 | 1, 2 |
| β-Selinene | 1475 | 1715 | 0.5 | 0.9 | 1, 2 |
| Germacrene D | 1477 | 1726 | --- | 0.6 | 1, 2 |
| γ-Muurolene | 1478 | 1704 | 0.4 | 2.0 | 1, 2 |
| (*E*)-β-Ionone | 1482 | 1957 | 3.5 | --- | 1, 2, 3 |
| *ar*-Curcumene | 1483 | 1784 | --- | 1.1 | 1, 2 |
| Dihydroactinidiolide | 1485 | 2354 | 1.3 | --- | 1, 2 |
| Viridiflorene | 1491 | 1695 | --- | 0.9 | 1, 2 |
| Valencene | 1495 | 1740 | t | 1.2 | 1, 2 |
| α-Selinene | 1498 | 1744 | 0.5 | 0.4 | 1, 2 |
| α-Muurolene | 1500 | 1740 | 0.2 | 1.3 | 1, 2 |
| (*E*,*E*)-α-Farnesene | 1505 | 1758 | --- | 0.6 | 1, 2 |
| γ-Cadinene | 1515 | 1776 | 1.2 | 2.9 | 1, 2 |
| 1S-*cis*-Calamenene | 1520 | 1839 | 0.3 | 1.5 | 1, 2 |
| δ-Cadinene | 1526 | 1773 | 0.1 | 3.0 | 1, 2 |
| α-Calacorene | 1541 | 1941 | t | 0.9 | 1, 2 |
| Ledol | 1565 | 2057 | 0.6 | 0.6 | 1, 2 |
| (*E*)-Nerolidol | 1566 | 2050 | --- | 1.4 | 1, 2 |
| Dodecanoic acid | 1568 | 2467 | 0.1 | --- | 1, 2, 3 |
| Spathulenol | 1578 | 2150 | 1.9 | 0.7 | 1, 2 |
| Caryophyllene oxide | 1580 | 2008 | --- | 0.8 | 1, 2, 3 |
| Tridecan-2-one | 1580 | 1815 | 0.3 | --- | 1, 2 |
| Globulol | 1585 | 2098 | 0.2 | 0.4 | 1, 2 |
| Viridiflorol | 1591 | 2104 | --- | 0.9 | 1, 2 |
| Humulene epoxide II | 1605 | 2011 | --- | 0.5 | 1, 2 |
| *epi*-Globulol | 1629 | 2025 | --- | 0.6 | 1, 2 |

**(Table 7) Contd.…**

| Compound | Ki[a] | Ki[b] | *S. hierosolymitana*[c] % | *S. multicaulis* var. *simplicifolia* % | Identification[d] |
|---|---|---|---|---|---|
| T-Cadinol | 1640 | 2187 | 1.2 | --- | 1, 2 |
| T-Muurolol | 1642 | 2209 | 0.6 | 0.5 | 1, 2 |
| Cubenol | 1644 | 2080 | --- | 0.6 | 1, 2 |
| Torreyol | 1645 | 2145 | --- | 0.1 | 1, 2 |
| α-Cadinol | 1649 | 2255 | 0.5 | 0.8 | 1, 2 |
| β-Eudesmol | 1650 | 2257 | --- | 0.4 | 1, 2 |
| Tetradecanol | 1672 | 2175 | 0.2 | --- | 1, 2 |
| Cadalene | 1677 | 2256 | 0.1 | 1.5 | 1, 2 |
| Pentadecan-2-one | 1694 | 2031 | 0.7 | --- | 1, 2 |
| Tetradecanoic acid | 1768 | 2672 | 1.5 | --- | 1, 2, 3 |
| 14-Hydroxy-α-humulene | 1780 | 2478 | --- | t | 1, 2 |
| Hexahydrofarnesyl acetone | 1835 | 2131 | 5.3 | 1.3 | 1, 2 |
| Pentadecanoic acid | 1873 | 2740 | 0.2 | --- | 1, 2, 3 |
| (E,E)-Farnesyl acetone | 1918 | 2384 | 1.2 | --- | 1, 2 |
| Phytol | 1950 | 2622 | 4.8 | 0.6 | 1, 2 |
| Palmitic acid | 1957 | 2931 | 12.5 | 1.2 | 1, 2, 3 |
| (*Z*,*Z*,*Z*)-9,12,15-Octadecatrienoic acid | 2099 | 3195 | 2.2 | t | 1, 2, 3 |
| (*Z*,*Z*)-9,12-Octadecadienoic acid | 2104 | 3160 | 3.3 | --- | 1, 2, 3 |
| (*Z*)-9-Octadecenoic acid | 2120 | 3157 | 1.6 | --- | 1, 2, 3 |
| Tetracosane | 2400 | 2400 | 0.1 | --- | 1, 2, 3 |
| Pentacosane | 2500 | 2500 | 0.5 | 0.7 | 1, 2, 3 |
| Hexacosane | 2600 | 2600 | 0.2 | --- | 1, 2, 3 |
| Heptacosane | 2700 | 2700 | 1.0 | 0.7 | 1, 2, 3 |
| Octacosane | 2800 | 2800 | t | --- | 1, 2, 3 |
| Nonacosane | 2900 | 2900 | 0.8 | 0.9 | 1, 2 |
| Triacontane | 3000 | 3000 | t | --- | 1, 2, 3 |
| Entriacontane | 3100 | 3100 | 0.5 | --- | 1, 2, 3 |
| Dotriacontane | 3200 | 3200 | t | --- | 1, 2, 3 |
| Total | | | 86.6 | 90.8 | |

The analyses were carried out in triplicate; [a]: Kovats retention index on HP-5 MS column; [b]: Kovats retention index on HP Innowax; [c] --- = absent; t = trace, less than 0.05%; [d]: Identification based on: 1 = Kovats retention index, 2 = mass spectrum, 3 = coinjection with authentic compound.

**Table 8. Effects of Different Doses of Essential Oils of *Salvia hierosolymitana* and *S. multicaulis* var. *simplicifolia* on Germination of *Raphanus sativus* and *Lepidium sativum*. The Data are Expressed as Mean of Three Replicates ± SD**

| ***Raphanus sativus*** | | |
|---|---|---|
| **Germinated Seeds** | | |
| | *Salvia hierosolymitana* | *Salvia multicaulis var. simplicifolia* |
| **Control** | 12.67 ± 1.51 | 10.67 ± 1.37 |
| **0.062 µg/mL** | 13.33 ± 1.15 | 13.00 ± 1.00 *** |
| **0.125 µg/mL** | 13.33 ± 0.58 | 11.00 ± 2.00 |
| **0.250 µg/mL** | 13.67 ± 0.58 | 12.33 ± 1.53 |
| **0.625 µg/mL** | 8.33 ± 2.31* | 12.67 ± 2.52 |
| **1.25 µg/mL** | 11.67 ± 1.53 | 12.00 ± 1.00 |
| **2.50 µg/mL** | 12.00 ± 0.00 | 11.33 ± 1.53 |
| ***Lepidium sativum*** | | |
| **Germinated Seeds** | | |
| | *Salvia hierosolymitana* | *Salvia multicaulis var. simplicifolia* |
| **Control** | 11.17 ± 2.04 | 11.17 ± 1.47 |
| **0.062 µg/mL** | 11.33 ± 1.15 | 11.33 ± 2.08 |
| **0.125 µg/mL** | 11.67 ± 4.16 | 8.33 ± 2.08 * |
| **0.250 µg/mL** | 12.00 ± 2.00 | 10.33 ± 2.52 |
| **0.625 µg/mL** | 12.00 ± 1.73 | 12.00 ± 2.65 |
| **1.25 µg/mL** | 11.67 ± 2.08 | 12.00 ± 1.73 |
| **2.50 µg/mL** | 12.33 ± 0.58 | 10.67 ± 0.58 |

The values, followed by * (*p < 0.05; **p < 0.01, ***p < 0.001), are statistically different according to the Student's *t* test.

**Table 9. Effects of Different Doses of Essential Oils of *Salvia hierosolymitana* and *S. multicaulis* var. *simplicifolia* on Radical Elongation of *Raphanus sativus* and *Lepidium sativum*. The Data are Expressed as Mean of Three Replicates ± SD**

| ***Raphanus sativus*** | | |
|---|---|---|
| **Radicle Length (cm ± SD)** | | |
| | *Salvia hierosolymitana* | *Salvia multicaulis var. simplicifolia* |
| **Control** | 3.14 ± 2.24 | 3.89 ± 2.39 |
| **0.062 µg/mL** | 2.60 ± 1.59 | 3.34 ± 2.03 |
| **0.125 µg/mL** | 2.80 ± 2.01 | 2.62 ± 1.77*** |
| **0.250 µg/mL** | 3.37 ± 2.00 | 3.18 ± 1.31 |
| **0.625 µg/mL** | 2.71 ± 1.81 | 4.20 ± 2.62 |
| **1.25 µg/mL** | 3.04 ± 1.80 | 2.13 ± 1.97*** |
| **2.50 µg/mL** | 2.80 ± 2.07 | 3.29 ± 2.02 |
| ***Lepidium sativum*** | | |
| **Radicle Length (cm ± SD)** | | |
| | *Salvia hierosolymitana* | *Salvia multicaulis var. simplicifolia* |
| **Control** | 3.47 ± 1.78 | 3.21 ± 1.60 |

**(Table 9) Contd….**

| *Lepidium sativum* | | |
|---|---|---|
| **Radicle Length (cm ± SD)** | | |
| **0.062 µg/mL** | 3.08 ± 1.58 | 2.64 ± 1.67 |
| **0.125 µg/mL** | 3.31 ± 2.36 | 4.05 ± 2.51 |
| **0.250 µg/mL** | 3.19 ± 1.67 | 3.61 ± 1.63 |
| **0.625 µg/mL** | 3.25 ± 1.80 | 4.12 ± 1.34** |
| **1.25 µg/mL** | 3.18 ± 1.60 | 3.83 ± 1.85 |
| **2.50 µg/mL** | 2.99 ± 1.51 | 2.97 ± 1.82 |

The values, followed by * (*p < 0.05; **p < 0.01, ***p < 0.001), are statistically different according to the Student's *t* test.

**Table 10. Essential Oil Compositions (%) of *Salvia africana*, *Salvia elegans*, *Salvia greggii*, *Salvia mellifera* and *Salvia munzii***

| Compound | Ki[a] | Ki[b] | *S. africana*[c] % | *S. elegans* % | *S. greggii* % | *S. mellifera* % | *S. munzii* % | Identi-fication[d] |
|---|---|---|---|---|---|---|---|---|
| Tricyclene | 925 | 1013 | 0.7 | 0.2 | --- | 0.2 | 0.3 | 1, 2 |
| α-Thujene | 928 | 1035 | 0.2 | --- | --- | 0.3 | --- | 1, 2 |
| α-Pinene | 938 | 1032 | --- | --- | --- | 9.2 | --- | 1, 2, 3 |
| Camphene | 953 | 1076 | --- | 0.2 | --- | 0.6 | --- | 1, 2, 3 |
| Sabinene | 973 | 1132 | 0.4 | 0.3 | --- | 0.6 | --- | 1, 2 |
| β-Pinene | 980 | 1118 | 0.8 | 0.7 | 0.2 | --- | --- | 1, 2, 3 |
| Myrcene | 993 | 1174 | --- | --- | --- | 2.0 | --- | 1, 2 |
| α-Phellandrene | 1005 | 1150 | --- | --- | --- | 0.1 | --- | 1, 2, 3 |
| δ-3-Carene | 1008 | 1160 | 1.6 | --- | --- | --- | --- | 1, 2, 3 |
| α-Terpinene | 1013 | 1189 | 1.7 | 0.1 | | 0.8 | 0.1 | 1, 2, 3 |
| *o*-Cymene | 1020 | 1187 | --- | 0.1 | 0.2 | 0.5 | 0.1 | 1, 2, 3 |
| *p*-Cymene | 1025 | 1280 | 21.2 | --- | --- | --- | --- | 1, 2, 3 |
| β-Phellandrene | 1029 | 1218 | --- | 0.4 | --- | --- | --- | 1, 2, 3 |
| Limonene | 1030 | 1203 | 0.4 | 1.1 | 0.4 | 2.2 | 1.4 | 1, 2, 3 |
| 1,8-Cineole | 1034 | 1213 | 0.2 | 0.4 | 0.2 | 39.8 | 0.2 | 1, 2, 3 |
| (*Z*)-β-Ocimene | 1038 | 1243 | 1.1 | 2.2 | 0.1 | 0.4 | 5.7 | 1, 2 |
| (*E*)-β-Ocimene | 1049 | 1262 | --- | 0.1 | 0.1 | 0.2 | 0.2 | 1, 2 |
| γ-Terpinene | 1057 | 1256 | 15.5 | 0.1 | 0.1 | 2.0 | 0.2 | 1, 2, 3 |
| *cis*-Sabinene hydrate | 1063 | 1556 | 0.2 | 0.1 | 0.1 | 0.2 | 0.1 | 1, 2 |
| *trans*-Linalool oxide | 1085 | 1455 | --- | 0.1 | 0.1 | --- | 0.1 | 1, 2 |
| *trans*- Sabinene hydrate | 1093 | 1474 | 1.3 | --- | --- | 1.0 | --- | 1, 2 |
| *cis*-Thujone | 1105 | 1430 | 0.2 | 38.7 | 43.4 | 0.2 | 33.3 | 1, 2 |
| 2-Phenyl ethyl alcool | 1113 | 1925 | 0.2 | --- | 3.3 | --- | 2.0 | 1, 2, 3 |
| *trans*-Thujone | 1115 | 1449 | 0.4 | --- | --- | --- | --- | 1, 2 |
| *cis-p* -Menth-2-en-1-ol | 1128 | 1638 | 0.2 | 0.1 | 0.1 | --- | --- | 1, 2 |

**(Table 10) Contd….**

| Compound | Ki[a] | Ki[b] | *S. africana*[c] % | *S. elegans* % | *S. greggii* % | *S. mellifera* % | *S. munzii* % | Identi-fication[d] |
|---|---|---|---|---|---|---|---|---|
| Camphor | 1145 | 1532 | 0.2 | 4.6 | 4.2 | 12.2 | 27.2 | 1, 2, 3 |
| Pinocarvone | 1165 | 1587 | 0.1 | --- | --- | --- | --- | 1, 2 |
| Borneol | 1167 | 1719 | 0.4 | --- | --- | --- | --- | 1, 2, 3 |
| Terpinen -4-ol | 1176 | 1611 | 1.0 | 0.7 | 0.7 | 2.0 | 0.6 | 1, 2, 3 |
| *p*-Cymen-8-ol | 1185 | 1856 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 1, 2 |
| α-Terpineol | 1189 | 1706 | 0.5 | 1.6 | 2.0 | 0.7 | 1.2 | 1, 2 |
| Verbenone | 1204 | 1723 | 0.1 | --- | --- | --- | --- | 1, 2 |
| *trans*-Carveol | 1217 | 1845 | 0.1 | --- | --- | 0.1 | --- | 1, 2 |
| Myrtenyl acetate | 1227 | 1698 | --- | --- | --- | 0.1 | --- | 1, 2 |
| Geraniol | 1235 | 1857 | --- | 6.5 | 3.4 | 0.1 | 4.0 | 1, 2 |
| Neral | 1240 | 1656 | --- | 0.7 | 0.5 | --- | 0.6 | 1, 2 |
| Carvone | 1241 | 1752 | --- | --- | 0.1 | --- | --- | 1, 2, 3 |
| Geranial | 1267 | 1712 | | 1.0 | 0.5 | --- | 0.5 | 1, 2, 3 |
| Bornyl acetate | 1284 | 1597 | 1.7 | 1.0 | 1.2 | 0.5 | 0.3 | 1,2 |
| Thymol | 1293 | 2198 | 0.8 | --- | 1.6 | --- | 1.1 | 1, 2, 3 |
| Carvacrol | 1299 | 2239 | 0.5 | 0.6 | 0.8 | --- | 0.4 | 1, 2, 3 |
| δ-Elemene | 1335 | 1476 | | 0.1 | 0.1 | --- | 0.1 | 1, 2 |
| α-Cubebene | 1352 | 1466 | 0.2 | 0.1 | 0.4 | --- | 0.1 | 1, 2 |
| (*Z*)-Isoeugenol | 1353 | 2186 | 0.2 | 0.1 | --- | 0.1 | 0.1 | 1, 2 |
| Citronellyl acetate | 1358 | 1662 | --- | --- | 0.1 | --- | --- | 1, 2 |
| Neryl acetate | 1367 | 2097 | --- | 0.2 | 0.2 | --- | 0.1 | 1, 2 |
| Geranyl acetate | 1379 | 1765 | --- | 6.9 | 8.7 | --- | 2.0 | 1, 2 |
| β-Elemene | 1387 | 1600 | --- | 0.4 | 0.4 | --- | 0.2 | 1, 2 |
| α-Gurjunene | 1408 | 1529 | 0.2 | 0.1 | --- | --- | --- | 1, 2 |
| Longifolene | 1411 | 1576 | --- | --- | 0.1 | --- | --- | 1, 2 |
| β-Caryophyllene | 1415 | 1612 | 0.4 | 0.2 | 0.1 | 0.9 | 0.1 | 1, 2 |
| Aromadendrene | 1422 | 1628 | 0.4 | 0.1 | | 0.1 | 0.1 | 1, 2 |
| β-Gurjunene | 1431 | 1632 | 0.2 | | 0.1 | 0.1 | --- | 1, 2 |
| γ-Elemene | 1434 | 1650 | --- | --- | --- | 0.4 | --- | 1, 2 |
| α-Guaiene | 1437 | 1530 | 1.0 | 0.5 | --- | 0.1 | 0.1 | 1, 2 |
| trans-Bergamotene | 1438 | | --- | --- | --- | 0.1 | | 1, 2 |
| α-Humulene | 1455 | 1689 | 0.4 | 0.3 | --- | 0.2 | 0.2 | 1, 2 |
| allo-Aromadendrene | 1463 | 1661 | --- | 0.2 | 0.2 | 0.1 | --- | 1, 2 |
| γ-Gurjunene | 1473 | 1687 | 0.1 | --- | --- | --- | --- | 1, 2 |
| Germacrene D | 1477 | 1726 | 0.1 | 0.2 | 0.2 | 0.1 | 0.2 | 1, 2 |
| γ-Muurolene | 1478 | 1704 | --- | 0.1 | 0.1 | 0.1 | 0.1 | 1, 2 |

**(Table 10) Contd….**

| Compound | Ki[a] | Ki[b] | *S. africana*[c] % | *S. elegans* % | *S. greggii* % | *S. mellifera* % | *S. munzii* % | Identification[d] |
|---|---|---|---|---|---|---|---|---|
| cis-β-Guaiene | 1490 | 1694 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 1,2 |
| Biciclogermacrene | 1491 | 1756 | --- | 2.5 | 1.7 | | 1.1 | 1, 2 |
| Valencene | 1495 | 1741 | 0.4 | 0.5 | 0.4 | 0.2 | 0.3 | 1, 2 |
| α-Selinene | 1498 | 1744 | --- | --- | | 0.4 | --- | 1, 2 |
| α-Muurolene | 1500 | 1740 | 0.4 | 1.8 | 2.3 | 0.1 | 1.4 | 1, 2 |
| β-Himachalene | 1505 | 1706 | 0.4 | 0.1 | 0.1 | 0.3 | --- | 1, 2 |
| β-Bisabolene | 1510 | 1743 | --- | --- | | 0.7 | --- | 1, 2 |
| γ-Cadinene | 1515 | 1776 | 2.8 | 1.5 | 1.3 | 0.3 | 1.0 | 1, 2 |
| Cubebol | 1517 | 1957 | 0.2 | 0.2 | | 0.1 | --- | 1, 2 |
| cis-Calamenene | 1520 | 1839 | --- | 0.1 | 0.1 | --- | --- | 1, 2 |
| Selina-3,7(11)-diene | 1524 | | 1.7 | --- | --- | 0.5 | --- | 1, 2 |
| δ-Cadinene | 1526 | 1773 | 4.6 | 11.5 | 14.0 | 0.9 | 8.9 | 1, 2 |
| α-Cadinene | 1535 | 1745 | --- | 0.3 | 0.3 | --- | 0.2 | 1, 2 |
| Cadina-1,4-diene | 1538 | 1799 | --- | 0.1 | 0.1 | --- | 0.1 | 1, 2 |
| α-Calacorene | 1541 | 1941 | --- | --- | 0.1 | --- | --- | 1, 2 |
| Germacrene B | 1544 | 1854 | 0.2 | --- | --- | 1.1 | --- | 1, 2 |
| Germacrene D-4-ol | 1577 | 2069 | 0.5 | --- | --- | 0.5 | --- | 1,2 |
| Spathulenol | 1578 | 2150 | --- | 0.2 | --- | --- | --- | 1, 2 |
| Caryophyllene oxide | 1580 | 2008 | 1.3 | --- | --- | 1.4 | --- | 1, 2, 3 |
| Globulol | 1585 | 2098 | 0.2 | --- | --- | 1.8 | 0.2 | 1, 2 |
| Viridiflorol | 1591 | 2104 | 0.2 | --- | --- | --- | --- | 1, 2 |
| β-Oplopenone | 1608 | 2100 | --- | 0.2 | 0.1 | 0.8 | 0.1 | 1, 2 |
| 1-epi-Cubenol | 1625 | 2088 | 2.9 | 0.2 | 0.2 | | 0.1 | 1, 2 |
| τ-Cadinol | 1640 | 2187 | 13.6 | 0.9 | 0.8 | 0.4 | 0.3 | 1, 2 |
| τ-Muurolol | 1642 | 2209 | --- | 1.4 | 1.1 | 0.4 | 0.5 | 1, 2 |
| α-Cadinol | 1649 | 2255 | --- | --- | --- | 1.9 | --- | 1, 2 |
| α-Eudesmol | 1652 | 2250 | 10.7 | --- | --- | --- | --- | 1, 2 |
| **Total** | | | **95.4** | **92.9** | **96.9** | **90.4** | **97.5** | |

The analyses were carried out in triplicate; [a]: Kovats retention index on HP-5 MS column; [b]: Kovats retention index on HP Innowax; [c] --- = absent; [d]: Identification based on: 1 = Kovats retention index, 2 = mass spectrum, 3 = coinjection with authentic compound.

not of garden cress, while *S. africana* oil was inactive towards both seeds.

*Teucrium* is a genus of perennial plants which belongs to the Lamiaceae family; it is represented by more than 340 species, distributed mainly in the Mediterranean basin. We analyzed the chemical composition of the essential oils of four different species of *Teucrium* [*T. arduini* L., *T. maghrebinum* Greuter et Burdet, *T. montbretii* Benth. ssp. *heliotropiifolium*, *T. polium* L. ssp. *capitatum* (L.) Arcangeli] and carried out *in vitro* experiments in order to verify their possible phytotoxic effects [26].

In the four oils, 131 compounds in all were identified (Table **13**): 53 for oil of *T. arduini* (86.2% of the total oil), 71 for *T. maghrebinum* (94.0% of the oil), 51 for *T. montbretii* (93.4% of the oil) and 89 for *T. polium* (92.4% of the oil). The oil of *T. arduini* comprised mainly sesquiterpenes (52.2%), particularly sesquiterpene hydrocarbons (30.8%). In particular, 21 sesquiterpene hydrocarbons were present in the oil, with a prevalence of caryophyllene (10.0%) and

**Table 11. Effects of Different Doses of Essential oils of *Salvia africana, Salvia elegans, Salvia greggii*, *Salvia mellifera* and *Salvia munzii* on Germination of *Raphanus sativus* and *Lepidium sativum*. The Data are Expressed as Mean of Three Replicates ± SD**

| ***Raphanus sativus*** | | | | | |
|---|---|---|---|---|---|
| **Germination (Number of Seeds)** | | | | | |
| | *Salvia africana* | *Salvia elegans* | *Salvia greggii* | *Salvia mellifera* | *Salvia munzii* |
| **Control** | 9.3 ± 1.1 | 9.3 ± 1.1 | 9.3 ± 1.1 | 9.3 ± 1.1 | 9.3 ± 1.1 |
| **0.06 µg/mL** | 9.7 ± 0.6 | 7.7 ± 2.0 | 7.3 ± 1.5 | 10 ± 0 | 9.7 ± 0.6 |
| **0.125 µg/mL** | 9.0 ± 1.0 | 8.7 ± 1.5 | 8.0 ± 1.7 | 10 ± 0 | 10 ± 0 |
| **0.25 µg/mL** | 8.7 ± 1.5 | 7.6 ± 0.6 | 8.7 ± 1.5 | 8.7 ± 0.6 | 9.0 ± 1.0 |
| **0.625 µg/mL** | 9.7 ± 0.6 | 7.6 ± 0.6 | 7.6 ± 0.6 | 8.7 ± 1.5 | 9.0 ± 1.0 |
| **1.25 µg/mL** | 8.7 ± 1.1 | 7.6 ± 0.6 | 6.3 ± 0.6 | 8.3 ± 1.5 | 8.7 ± 1.1 |
| ***Lepidium sativum*** | | | | | |
| **Germination (Number of Seeds)** | | | | | |
| | *Salvia africana* | *Salvia elegans* | *Salvia greggii* | *Salvia mellifera* | *Salvia munzii* |
| **Control** | 9.3 ± 0.6 | 9.3 ± 0.6 | 9.3 ± 0.6 | 9.3 ± 0.6 | 9.3 ± 0.6 |
| **0.06 µg/mL** | 9.7 ± 0.6 | 8.3 ± 1.5 | 9.3 ± 1.1 | 8.7 ± 0.6 | 9.7 ± 0.6 |
| **0.125 µg/mL** | 9.7 ± 0.6 | 8.7 ± 1.5 | 8.0 ± 1.7 | 8.7 ± 0.6 | 9.0 ± 1.0 |
| **0.25 µg/mL** | 10 ± 0 | 6.0 ± 1.0* | 7.0 ± 1.0 | 7.0 ± 1.0 | 10 ± 0 |
| **0.625 µg/mL** | 10 ± 0 | 0 ± 0 | 1 ± 0 | 6.0 ± 1.0* | 0 ± 0 |
| **1.25 µg/mL** | 9.0 ± 1.0 | 0 ± 0 | 0 ± 0 | 6.3 ± 0.6 | 0 ± 0 |

The values, followed by * (*p < 0.05; **p < 0.01, ***p < 0.001), are statistically different according to the Student's *t* test.

**Table 12. Effects of Different Doses of Essential Oils of *Salvia africana*, *Salvia elegans*, *Salvia greggii*, *Salvia mellifera* and *Salvia munzii* on Radical Elongation of *Raphanus sativus* and *Lepidium sativum*. The Data are Expressed as Mean of Three Replicates ± SD**

| ***Raphanus sativus*** | | | | | |
|---|---|---|---|---|---|
| **Radicle Length (cm ± SD)** | | | | | |
| | *Salvia africana* | *Salvia elegans* | *Salvia greggii* | *Salvia mellifera* | *Salvia munzii* |
| **Control** | 3.4 ± 2.0 | 3.4 ± 2.0 | 3.4 ± 2.0 | 3.4 ± 2.0 | 3.4 ± 2.0 |
| **0.06 µg/mL** | 2.6 ± 1.0 | 2.7 ± 1.3 | 3.4 ± 1.9 | 2.4 ± 1.1* | 2.1 ± 1.3** |
| **0.125 µg/mL** | 3.2 ± 1.6 | 2.1 ± 0.9** | 1.9 ± 1.3 | 2.6 ± 1.4 | 2.3 ± 0.8** |
| **0.25 µg/mL** | 2.5 ± 1.5 | 1.9 ± 1.1** | 2.7 ± 1.6 | 2.9 ± 1.7 | 1.9 ± 1.1** |
| **0.625 µg/mL** | 3.1 ± 2.0 | 1.2 ± 0.9*** | 2.2 ± 1.2* | 2.2 ± 0.9** | 2.1 ± 1.2** |
| **1.25 µg/mL** | 2.5 ± 1.4 | 1.4 ± 0.6*** | 1.3 ± 0.5*** | 1.9 ± 1.4** | 1.2 ± 0.7*** |
| ***Lepidium sativum*** | | | | | |
| **Radicle Length (cm ± SD)** | | | | | |
| | *Salvia africana* | *Salvia elegans* | *Salvia greggii* | *Salvia mellifera* | *Salvia munzii* |
| **Control** | 2.5 ± 0.9 | 2.5 ± 0.9 | 2.5 ± 0.9 | 2.5 ± 0.9 | 2.5 ± 0.9 |
| **0.06 µg/mL** | 4.1 ± 2.4** | 1.7 ± 0.8** | 2.4 ± 0.9 | 2.3 ± 0.7 | 2.3 ± 0.7 |

**(Table 12) Contd….**

| *Lepidium sativum* | | | | | |
|---|---|---|---|---|---|
| **Radicle Length (cm ± SD)** | | | | | |
| **0.125 µg/mL** | 2.6 ± 0.8 | 1.1 ± 0.8*** | 2.9 ± 1.5 | 3.3 ± 1.9 | 2.1 ± 0.9 |
| **0.25 µg/mL** | 2.4 ± 0.9 | 0.8 ± 0.4*** | 2.5 ± 0.9 | 2.4 ± 1.8 | 0.8 ± 0.6*** |
| **0.625 µg/mL** | 2.6 ± 0.9 | 0.0 ± 0.0*** | 2.5*** | 2.3 ± 0.9 | 0.0 ± 0.0*** |
| **1.25 µg/mL** | 2.6 ± 1.1 | 0.0 ± 0.0*** | 0.0 ± 0.0*** | 2.6 ± 1.5 | 0.0 ± 0.0*** |

The values, followed by * (*p < 0.05; **p < 0.01, ***p < 0.001), are statistically different according to the Student's *t* test.

**Table 13. Essential oil Compositions (%) of *T. arduini*, *T. maghrebinum*, *T. montbretii* ssp. *heliotropiifolium* and *T. polium* ssp. *capitatum***

| Compound | Ki[a] | Ki[b] | *T. arduini*[c] | *T. maghrebinum* | *T. montbretii* ssp. *heliotropiifolium* | *T. polium* ssp. *capitatum* | Identification[d] |
|---|---|---|---|---|---|---|---|
| (*E*)-2-Hexenal | 854 | 1231 | --- | t | --- | --- | 1, 2 |
| α-Thujene | 930 | 1014 | --- | 0.2 | --- | 0.2 | 1, 2 |
| α-Pinene | 938 | 1075 | --- | 1.6 | --- | 0.2 | 1, 2, 3 |
| Camphene | 953 | 1076 | --- | 0.3 | --- | --- | 1, 2, 3 |
| Benzaldehyde | 963 | 1543 | --- | 0.2 | --- | --- | 1, 2, 3 |
| Sabinene | 973 | 1132 | --- | --- | --- | 0.3 | 1, 2 |
| 1-Octen-3-one | 975 | 1312 | --- | 0.3 | --- | --- | 1, 2 |
| 1-Octen-3-ol | 977 | 1425 | 0.5 | 0.3 | 0.1 | 0.1 | 1, 2 |
| β-Pinene | 978 | 1118 | --- | 1.9 | --- | --- | 1, 2, 3 |
| Octan-3-ol | 992 | 1394 | --- | 0.4 | --- | --- | 1, 2, 3 |
| Myrcene | 993 | 1174 | --- | 0.5 | --- | ---t | 1, 2, 3 |
| 2-Pentylfuran | 1002 | 1244 | t | --- | --- | --- | 1, 2 |
| α-Terpinene | 1012 | 1189 | --- | --- | --- | --- | 1, 2, 3 |
| *p*-Cymene | 1025 | 1278 | --- | --- | --- | 0.5 | 1, 2, 3 |
| Limonene | 1030 | 1203 | --- | 4.4 | --- | --- | 1, 2, 3 |
| Acetophenone | 1036 | 1645 | --- | --- | 0.1 | --- | 1, 2 |
| (*Z*)-β-Ocimene | 1038 | 1245 | --- | --- | --- | --- | 1, 2 |
| Phenylacetaldehyde | 1048 | 1663 | 0.1 | 0.4 | 0.1 | 0.1 | 1, 2, 3 |
| *cis*-Linalool oxide, furanoid | 1062 | 1450 | --- | --- | 0.1 | 0.5 | 1, 2 |
| *cis*-Sabinene hydrate | 1063 | 1555 | --- | --- | --- | 0.2 | 1, 2 |
| *trans*-Linalool oxide, furanoid | 1076 | 1478 | --- | --- | 0.1 | 0.1 | 1, 2 |
| *trans*-Sabinene hydrate | 1093 | 1474 | --- | --- | --- | 0.1 | 1, 2 |
| Linalool | 1098 | 1553 | 1.6 | 1.3 | 2.7 | 1.0 | 1, 2, 3 |
| α-Campholenal | 1128 | 1497 | --- | 0.4 | --- | --- | 1, 2 |
| *cis*-Sabinol | 1135 | 1789 | --- | --- | --- | 1.7 | 1, 2 |
| Nopinone | 1136 | 1597 | --- | 0.1 | --- | 0.2 | 1, 2 |
| *cis*-Verbenol | 1144 | 1667 | --- | 0.4 | --- | 2.0 | 1, 2 |

**(Table 13) Contd….**

| Compound | Ki[a] | Ki[b] | *T. arduini*[c] | *T. maghrebinum* | *T. montbretii* ssp. *heliotropiifolium* | *T. polium* ssp. *capi-tatum* | Identification[d] |
|---|---|---|---|---|---|---|---|
| Sabina ketone | 1155 | 1652 | --- | --- | --- | 0.4 | 1, 2 |
| Pinocarvone | 1165 | 1587 | --- | 0.6 | --- | 0.1 | 1, 2 |
| Borneol | 1167 | 1719 | --- | --- | --- | 0.1 | 1, 2, 3 |
| Umbellulone | 1175 | 1656 | --- | --- | --- | 0.3 | 1, 2 |
| Terpineol-4 | 1176 | 1611 | --- | 0.4 | --- | 0.5 | 1, 2, 3 |
| α-Terpineol | 1189 | 1706 | --- | 0.6 | 0.2 | --- | 1, 2, 3 |
| Myrtenal | 1193 | 1648 | --- | t | --- | t | 1, 2, 3 |
| Myrtenol | 1196 | 1812 | --- | --- | --- | 1.2 | 1, 2 |
| *cis*-Verbenone | 1204 | 1723 | --- | 0.3 | --- | 4.0 | 1, 2 |
| α-Ionene | 1208 | | --- | --- | 0.2 | --- | 1, 2 |
| *trans*-Carveol | 1217 | 1845 | --- | 0.1 | --- | --- | 1, 2 |
| β-Cyclocitral | 1223 | 1629 | --- | t | --- | 0.1 | 1, 2 |
| *cis*-Carveol | 1226 | 1878 | --- | --- | --- | 0.6 | 1, 2 |
| Cumin aldehyde | 1232 | 1804 | --- | --- | --- | 0.1 | 1, 2 |
| Carvone | 1241 | 1750 | --- | 2.5 | --- | 0.3 | 1, 2 |
| Thymol | 1290 | 2198 | 0.2 | --- | --- | 0.1 | 1, 2, 3 |
| *p*-Menth-9-en-1-ol | 1291 | 1945 | 1.2 | --- | --- | --- | 1, 2 |
| *p*-Cymen-7-ol | 1293 | 2067 | --- | --- | --- | 1.5 | 1, 2 |
| Dihydroedulan I | 1296 | | 0.4 | 0.1 | --- | --- | 1, 2 |
| Carvacrol | 1297 | 2239 | --- | --- | 13.5 | 9.6 | 1, 2, 3 |
| *p*-Methoxyacetophenone | 1302 | 1797 | 2.3 | --- | --- | 1.5 | 1, 2, 3 |
| 4-Vinyl guaiacol | 1312 | 2180 | 1.8 | 2.0 | --- | 0.1 | 1, 2 |
| δ-Elemene | 1335 | 1476 | --- | 0.6 | --- | --- | 1, 2 |
| α-Longipinene | 1351 | | --- | --- | --- | 0.1 | 1, 2 |
| α-Cubebene | 1352 | 1466 | t | 0.8 | 0.4 | --- | 1, 2 |
| Eugenol | 1353 | 2186 | 0.5 | 1.6 | 0.8 | 0.5 | 1, 2, 3 |
| Cyclosativene | 1363 | 1492 | --- | --- | --- | --- | 1, 2 |
| α-Ylangene | 1372 | 1493 | --- | --- | 0.3 | --- | 1, 2 |
| α-Copaene | 1377 | 1503 | 0.6 | 0.8 | 0.6 | 1.0 | 1, 2 |
| (*E*)-β-Damascenone | 1380 | 1835 | 1.1 | 1.0 | 0.4 | 0.2 | 1, 2 |
| β-Cubebene | 1382 | 1547 | 0.7 | 2.5 | | 0.1 | 1, 2 |
| β-Bourbonene | 1385 | 1535 | 1.2 | 1.0 | 1.8 | 0.5 | 1, 2 |
| β-Elemene | 1387 | 1598 | 0.2 | --- | | 0.2 | 1, 2 |
| α-Elemene | 1396 | --- | --- | --- | 0.2 | --- | 1, 2 |
| α-Gurjunene | 1408 | 1529 | --- | --- | --- | 1.2 | 1, 2 |
| α-Funebrene | 1409 | 1510 | --- | --- | --- | 0.2 | 1, 2 |

**(Table 13) Contd….**

| Compound | Ki[a] | Ki[b] | *T. arduini*[c] | *T. maghrebinum* | *T. montbretii* ssp. *heliotropiifolium* | *T. polium* ssp. *capi-tatum* | Identification[d] |
|---|---|---|---|---|---|---|---|
| Caryophyllene | 1415 | 1612 | 10.0 | 4.9 | 8.2 | 10.1 | 1, 2, 3 |
| (*E*)-α-Ionone | 1419 | --- | 0.3 | --- | --- | --- | 1, 2, 3 |
| Aromadendrene | 1422 | 1628 | 0.2 | 0.6 | --- | 0.2 | 1, 2 |
| β-Gurjunene (Calarene) | 1423 | 1632 | --- | 0.3 | --- | 0.3 | 1, 2 |
| *epi*-Bicyclosesquiphellandrene | 1424 | --- | 0.6 | --- | --- | 0.7 | 1, 2 |
| β-Cedrene | 1430 | 1638 | --- | --- | 0.9 | --- | 1, 2 |
| γ-Elemene | 1436 | 1650 | 0.8 | 0.1 | --- | 0.1 | 1, 2 |
| β-Humulene | 1437 | 1674 | --- | t | --- | 0.3 | 1, 2 |
| (*E*)-β-Farnesene | 1452 | 1673 | t | 0.3 | --- | 0.1 | 1, 2 |
| α-Humulene | 1455 | 1689 | 3.1 | 0.9 | 2.8 | 3.4 | 1, 2 |
| *allo*-Aromadendrene | 1463 | 1661 | 1.9 | 0.5 | 2.8 | 0.4 | 1, 2 |
| Germacrene D | 1477 | 1726 | 5.8 | 14.3 | 3.7 | 3.9 | 1, 2 |
| γ-Muurolene | 1478 | 1704 | 1.0 | 0.3 | 1.0 | --- | 1, 2 |
| (*E*)-β-Ionone | 1482 | 1957 | 1.4 | 0.5 | --- | --- | 1, 2, 3 |
| *ar*-Curcumene | 1483 | 1784 | --- | --- | --- | 0.2 | 1, 2 |
| Dihydroactinidiolide | 1486 | 2354 | --- | 0.5 | 1.6 | --- | 1, 2 |
| α-Amorphene | 1487 | 1679 | 0.2 | 0.5 | 0.5 | 2.5 | 1, 2 |
| *cis*-β-Guaiene | 1490 | 1694 | --- | --- | --- | 1.5 | 1, 2 |
| Bicyclosesquiphellandrene | 1491 | 1626 | 0.2 | --- | 1.8 | 0.1 | 1, 2 |
| Bicyclogermacrene | 1492 | 1756 | 1.9 | --- | --- | 0.7 | 1, 2 |
| Valencene | 1494 | 1741 | --- | --- | 0.5 | 0.2 | 1, 2 |
| α-Muurolene | 1503 | 1740 | 0.5 | --- | 0.3 | 0.1 | 1, 2 |
| γ-Cadinene | 1515 | 1776 | 0.5 | 7.5 | --- | 0.1 | 1, 2 |
| 1-*endo*-Bourbonanol | 1520 | | --- | --- | 0.5 | --- | 1, 2 |
| δ-Cadinene | 1526 | 1773 | --- | 13.5 | 2.7 | 3.1 | 1, 2 |
| Cadina-1,4-diene | 1538 | 1799 | --- | 0.9 | | 0.2 | 1, 2 |
| α-Calacorene | 1541 | 1942 | --- | 0.3 | 0.2 | 0.2 | 1, 2 |
| Germacrene B | 1554 | 1856 | t | --- | --- | 0.6 | 1, 2 |
| Ledol | 1565 | 2057 | 0.8 | --- | 1.7 | --- | 1, 2 |
| (*E*)-Nerolidol | 1566 | 2050 | --- | 1.4 | --- | --- | 1, 2 |
| Longipinanol | 1572 | | --- | t | --- | --- | 1, 2 |
| Germacrene D 4-ol | 1577 | 2069 | --- | --- | --- | 3.0 | 1, 2 |
| Spathulenol | 1578 | 2150 | 5.8 | 1.8 | --- | 0.1 | 1, 2, 3 |
| Caryophyllene oxide | 1580 | 2008 | 7.7 | 4.0 | 8.8 | 5.0 | 1, 2, 3 |
| Globulol | 1588 | 2098 | --- | --- | --- | 0.2 | 1, 2 |
| Viridiflorol | 1591 | 2104 | 0.7 | --- | 2.0 | --- | 1, 2 |

**(Table 13) Contd….**

| Compound | Ki[a] | Ki[b] | *T. arduini*[c] | *T. maghrebinum* | *T. montbretii* ssp. *heliotropiifolium* | *T. polium* ssp. *capi-tatum* | Identification[d] |
|---|---|---|---|---|---|---|---|
| Widdrol | 1600 | | --- | --- | 1.4 | 0.1 | 1, 2 |
| Humulene epoxide II | 1605 | 2071 | --- | --- | 0.9 | 1.3 | 1, 2 |
| Cedrenol | 1606 | 2133 | 4.8 | --- | 0.1 | 0.1 | 1, 2 |
| Torreyol | 1645 | | --- | --- | --- | 6.5 | 1, 2 |
| α-Cadinol | 1649 | 2255 | --- | 1.9 | 0.7 | 4.0 | 1, 2 |
| Caryophyllenol II | 1650 | 2396 | --- | --- | 3.2 | 0.1 | 1, 2 |
| (*E*)-Isoelemicin | 1659 | 2403 | 1.6 | --- | --- | 0.2 | 1, 2 |
| Patchoulol | 1664 | | --- | --- | 0.5 | --- | 1, 2 |
| Cadalene | 1677 | 2256 | --- | 0.4 | 0.7 | 1.6 | 1, 2 |
| Germacrone | 1685 | | --- | t | --- | --- | 1, 2 |
| α-Bisabolol | 1686 | 2219 | t | 0.8 | --- | 0.3 | 1, 2 |
| (*Z*,*E*)-Farnesol | 1689 | 2276 | | 0.5 | --- | 0.2 | 1, 2 |
| Vulgarol B | 1691 | | --- | --- | 0.8 | --- | 1, 2 |
| *cis*(*Z*)-α-Bisabolene-epoxide | 1698 | | --- | --- | --- | 0.2 | 1, 2 |
| Heptadecane | 1700 | 1700 | --- | 0.2 | --- | 0.1 | 1, 2, 3 |
| Hexahydrofarnesylacetone | 1845 | 2131 | 3.8 | 2.8 | 2.6 | 0.8 | 1, 2 |
| Hexadecanoic acid | 1957 | 2931 | 9.3 | 1.8 | 10.7 | 0.1 | 1, 2, 3 |
| 13-*epi*-Manoyl oxide | 1963 | 2388 | --- | --- | 0.7 | --- | 1, 2 |
| Manoyl oxide | 1994 | | --- | --- | 0.5 | 0.1 | 1, 2 |
| Kaurene | 2048 | 2399 | | --- | --- | 0.8 | 1, 2 |
| Heptadecanoic acid | 2054 | 2975 | 0.1 | --- | --- | --- | 1, 2, 3 |
| (Z)-9-Octadecenoic acid | 2115 | | 0.1 | --- | --- | --- | 1, 2, 3 |
| (*Z*,*Z*)-9,12-Octadecadienoic acid | 2122 | 3157 | --- | 0.6 | 2.4 | 0.5 | 1, 2, 3 |
| Octadecanoic acid | 2172 | 3402 | 0.2 | 0.2 | --- | --- | 1, 2, 3 |
| Pentacosane | 2500 | 2500 | 1.0 | 0.8 | 1.9 | 0.7 | 1, 2 |
| Hexacosane | 2600 | 2600 | 0.2 | 0.2 | --- | --- | 1, 2 |
| Heptacosane | 2700 | 2700 | 4.0 | 1.5 | 1.7 | 1.9 | 1, 2 |
| Octacosane | 2800 | 2800 | 0.6 | 0.1 | 0.5 | | 1, 2 |
| Squalene | 2829 | | 0.3 | --- | --- | --- | 1, 2 |
| Nonacosane | 2900 | 2900 | 2.8 | 1.0 | 1.2 | 2.5 | 1, 2 |
| Triacontane | 3000 | 3000 | 0.4 | t | --- | 0.1 | 1, 2 |
| Hentriacontane | 3100 | 3100 | 1.2 | 0.5 | 1.3 | 1.2 | 1, 2 |
| **Total** | | | **86.2** | **94** | **93.4** | **92.4** | |

The analyses were carried out in triplicate; [a]: Kovats retention index on HP-5 MS column; [b]: Kovats retention index on HP Innowax; [c] --- = absent; t = trace, less than 0.05%; [d]: Identification based on: 1 = Kovats retention index, 2 = mass spectrum, 3 = coinjection with authentic compound.

germacrene D (5.8%). Seven oxygenated sesquiterpenoids were present in the oil, being the main constituent caryophyllene oxide (7.7%). Hydrocarbons were quite abundant (10.2%) and were constituted by almost heptacosane and nonacosane. Fatty acids (9.7%) were represented by hexadecanoic acid (9.3%), while hexahydrofarnesylacetone was the main constituent among carbonylic compounds (7.6%). In the oil of *T. maghrebinum* the most abundant compounds were germacrene D (14.3%), δ-cadinene (13.5%) and γ-cadinene (7.5%). On the whole, the oil was constituted mainly by sesquiterpenes (61.9%) and monoterpenes (15.6%). Sesquiterpene hydrocarbons (51.5%) prevailed over oxygen containing sesquiterpenes (10.4%). Twenty-three sesquiterpene hydrocarbons were present in the oil, with a prevalence of germacrene D (14.3%), and also δ-cadinene, γ-cadinene and caryophyllene. Among 8 oxygen containing sesquiterpenes, the most abundant was caryophyllene oxide. Among monoterpenes, 6 hydrocarbons accounted for the 8.9% of the total oil, with limonene as the main compound. In the essential oil of *T. montbretii*, the main fraction was constituted by sesquiterpenes (50.0%). Among these, sesquiterpene hydrocarbons (29.4%) prevailed on oxygen containing sesquiterpenes (20.6%). In the first fraction caryophyllene (8.2%), germacrene D (3.7%), *allo*-aromadendrene (2.8%) and α-humulene (2.8%) predominated, while among the 11 oxygen containing sesquiterpenes the most abundant compounds were caryophyllene oxide and caryophyllenol II. The phenols were quite abundant (14.3%) and were constituted almost entirely by carvacrol (13.5%). Fatty acids (13.1%) were mainly represented by hexadecanoic acid, while linalool was the main constituent of oxygenate monoterpenes (3.1%). In the oil of *T. polium* sesquiterpenes constituted also the main fraction and accounted for the 55.2% of the total oil with a prevalence of sesquiterpene hydrocarbons (33.9%) over oxygen containing sesquiterpenes (21.3%). Among the 30 sesquiterpene hydrocarbons, caryophyllene (10.1%), germacrene D (3.9%), α-humulene (3.4%) and δ-cadinene (3.1%) were the most abundant. In the other fraction, torreyol (6.5%), caryophyllene oxide (5.0%) and α-cadinol (4.0%) prevailed. Monoterpenes contributed for the 16.2% of the oil with a predominance of oxygen containing monoterpenes (15.0%), particularly *cis*-verbenone and *cis*-verbenol. The phenolic compounds (10.3%) were represented almost entirely by carvacrol (9.6%).

The oils affected differently the germination (Table **14**) and the radicle elongation (Table **15**) of radish and garden cress. Radicle elongation seemed to be more affected in comparison to germination. The germination of radish did not appeared sensitive to the four essential oils: only the essential oil of *T. polium*, at a dose of 1.25 μg/ml, significantly inhibited the germination of radish. The germination of garden cress did not appeared sensitive to the four essential oils, too: only the essential oil of *T. arduini*, at the highest dose tested, significantly inhibited the germination of garden cress. The radicle elongation of radish was significantly inhibited by the all oils: particularly, the essential oil of *T. arduini*, at the highest doses tested, inhibited the radicle elongation of radish, and in minor measure, of garden cress. The essential oil of *T. montbretii* inhibited only the radicle elongation of radish, at the dose of 1.25 μg/ml.

In continuation of our studies, we analyzed the chemical composition of the essential oils from *Hypericum perforatum* (section *Hypericum*), *H. perfoliatum* L. (section *Drosocarpiun*) and *H. hircinum* L. (section Androsaemum), exploiting also their possible phytotoxic effects on germination and early radicle elongation of radish and garden cress [29]. In the three oils, 111 compounds in all were identified: 53 for the oil of *H. hircinum* (93.7% of the total oil), 55 for *H. perforatum* (96.5% of the total oil) and 63 for *H. perfoliatum* (98.7% of the total oil). The components are listed in Table **16**: the main components of *H. perforatum* were germacrene D (17.1%), β-caryophyllene (12.3%) and γ-muurolene (11.1%). The major compounds of *H. hircinum* essential oil were *cis*-β-guajene (27.5%), δ-selinene (11.4%), *n*-nonane (10.2%). For *H. perfoliatum,* the major compounds were α-pinene (25.3%), thymol (15.8%), τ-cadinol (11.5%).

The oils did not affect very much the germination (Table **17**) and radicle elongation (Table **18**) of radish and garden cress: generally, germination of the two types of seeds was less sensitive to the three essential oils than radicle elongation; only the essential oil of *H. hircinum,* at the highest dose tested, inhibited the germination of garden cress. The essential oils of *H. hircinum* and *H. perforatum*, at the highest dose tested, inhibited radicle elongation of radish, while the essential oils of *H. perfoliatum* and *H. hircinum,* at the highest dose tested, significantly inhibited radicle elongation of garden cress.

Recently, we analyzed the chemical composition of the essential oil of *Helichrysum italicum* (Roth) Don ssp. *italicum*, collected in the National Park of Cilento and Diano Valley, examining also its possible phytotoxic effects against germination and early radicle elongation of *Raphanus sativus* and *Lepidium sativum*. Hydrodistillation yielded 0.02% of a pale yellow oil (on a dry mass basis). The volatile components of the essential oil and their percentages are shown in Table **19**: fourty-four compounds were identified, accounting for 90.0% of the total oil. Sesquiterpenes represented 74.3% of the total oil, while the monoterpenoid fraction accounted only for 1.1%. Oxygenated sesquiterpenes (73.6%) prevailed, being the major constituents *iso*-italicene epoxide (16.8%), β-costol (7.5%) and (*Z*)-α-*trans*-bergamotol (4.7%).

Tables **20** and **21** report the effects of this oil against germination (Table **20**) and initial radicle elongation (Table **21**) of radish and garden cress: that did not appear significantly sensitive to the essential oil. At doses ranging between of 2.5 and 0.25 μg/mL the essential oil significantly inhibited the radicle elongation of radish of about 30%. The roots were probably more sensitive than shoots to the phytotoxic activity of the oil: the process of germination was active while the oil probably affected the elongation process.

Consequently, we decided to study the activity of single monoterpenoids, main constituents of previous cited essential oils, in order to evaluate their biological activity linked to their chemical features, towards germination and radicle elongation of selected seeds [24]. The assayed compounds belonged to different chemical groups, e.g., alcohols, phenols, aldehydes, ketones, acetates, hydrocarbons and ethers. We tested the potential phytotoxic activity of each compound on seed germination and growth of the primary

**Table 14. Effects of Different Doses of Essential Oils of *T. arduini*, *T. maghrebinum*, *T. montbretii* ssp. *heliotropiifolium* and *T. polium* ssp. *capitatum* on Germination of *Raphanus sativus* and *Lepidium sativum*. The Data are Expressed as Mean of Three Replicates ± SD**

| ***Raphanus sativus*** | | | | |
|---|---|---|---|---|
| **Germinated Seeds** | | | | |
| | *T. arduini* | *T. maghrebinum* | *T. montbretii ssp. heliotropiifolium* | *T. polium ssp. capitatum* |
| **Control** | 6.2±1.2 | 6.2±1.2 | 6.2±1.2 | 6.2±1.2 |
| **0.06 µg/mL** | 4.3±1.2 | 6.3±0.6 | 5.0 ± 1.0 | 5.0±1.0 |
| **0.125 µg/mL** | 4.0±1.7 | 5.0±1.0 | 5.3 ± 1.2 | 4.3±1.2 |
| **0.25 µg/mL** | 6.3±1.2 | 5.3±0.6 | 4.7 ± 3.1 | 4.7±0.6 |
| **0.625 µg/mL** | 4.7±0.6 | 7.0±1.0 | 5.0 ± 0.0 | 5.7±1.5 |
| **1.25 µg/mL** | 5.3±1.5 | 5.7±1.2 | 6.7 ± 1.2 | 3.7±0.6* |
| **2.5 µg/mL** | 6.0±1.0 | 3.7±3.2 | 6.7 ± 0.6 | 5.7±0.6 |
| ***Lepidium sativum*** | | | | |
| **Germinated Seeds** | | | | |
| | *T. arduini* | *T. maghrebinum* | *T. montbretii ssp. heliotropi-ifolium* | *T. polium ssp. capitatum* |
| **Control** | 9.2±0.8 | 9.2±0.8 | 9.2±0.8 | 9.2±0.8 |
| **0.06 µg/mL** | 8.7±2.3 | 9.3±0.6 | 9.0±1.0 | 9.3±1.2 |
| **0.125 µg/mL** | 9.0±1.0 | 8.0±0.0 | 9.0±1.0 | 9.7±0.6 |
| **0.25 µg/mL** | 10.0±0.0 | 8.3±0.6 | 9.0±1.0 | 8.3±1.2 |
| **0.625 µg/mL** | 8.0±2.0 | 9.3±0.6 | 9.3±0.6 | 9.3±0.6 |
| **1.25 µg/mL** | 8.0±1.0 | 9.3±0.6 | 9.7±0.6 | 9.0±1.7 |
| **2.5 µg/mL** | 7.7±0.6* | 9.3±0.6 | 9.3±0.6 | 9.3±0.6 |

The values, followed by * (*p < 0.05; **p < 0.01, ***p < 0.001), are statistically different according to the Student's *t* test.

**Table 15. Effects of Different Doses of Essential oils of *T. arduini*, *T. maghrebinum*, *T. montbretii* ssp. *heliotropiifolium* and *T. polium* ssp. *capitatum* on Radical Elongation of *Raphanus sativus* and *Lepidium sativum*. The Data are Expressed as Mean of Three Replicates ± SD**

| ***Raphanus sativus*** | | | | |
|---|---|---|---|---|
| **Radicle Length (cm ± SD)** | | | | |
| | *T. arduini* | *T. maghrebinum* | *T. montbretii ssp. heliotropiifolium* | *T. polium ssp. capitatum* |
| **Control** | 0.5±0.3 | 0.5±0.3 | 0.5±0.3 | 0.5±0.3 |
| **0.06 µg/mL** | 0.3±0.2 | 0.2±0.2*** | 0.4 ± 0.2 | 0.5±0.2 |
| **0.125 µg/mL** | 0.4±0.1 | 0.4±0.3 | 0.4 ± 0.2 | 0.5±0.3 |
| **0.25 µg/mL** | 0.4±0.2 | 0.4±0.2 | 0.5 ± 0.3 | 0.6±0.3 |
| **0.625 µg/mL** | 0.3±0.2* | 0.5±0.3 | 0.4 ± 0.2 | 0.3±0.2* |
| **1.25 µg/mL** | 0.3±0.2* | 0.4±0.2 | 0.4 ± 0.2* | 0.4±0.2 |
| **2.5 µg/mL** | 0.3±0.2* | 0.4±0.2 | 0.4 ± 0.3 | 0.4±0.2 |

**(Table 15) Contd….**

| *Lepidium sativum* | | | | |
|---|---|---|---|---|
| **Radicle Length (cm ± SD)** | | | | |
| | *T. arduini* | *T. maghrebinum* | *T. montbretii ssp. heliotropi-ifolium* | *T. polium ssp. capitatum* |
| **Control** | 2.2±1.2 | 2.2±1.2 | 2.2±1.2 | 2.2±1.2 |
| **0.06 µg/mL** | 2.4±1.1 | 1.7±1.2* | 2.1±1.1 | 2.3±1.1 |
| **0.125 µg/mL** | 2.3±0.9 | 1.9±1.0 | 2.2±0.9 | 2.7±1.2 |
| **0.25 µg/mL** | 2.2±1.1 | 2.1±1.1 | 2.4±1.3 | 1.8±0.9* |
| **0.625 µg/mL** | 2.3±1.2 | 2.4±1.0 | 2.5±0.9 | 2.2±1.0 |
| **1.25 µg/mL** | 2.4±1.0 | 1.9±0.9 | 2.2±1.1 | 1.9±1.1 |
| **2.5 µg/mL** | 1.7±1.0* | 2.3±1.0 | 2.2±0.9 | 2.5±0.9 |

The values, followed by * (*p < 0.05; **p < 0.01, ***p < 0.001), are statistically different according to the Student's *t* test.

**Table 16. Essential oil Compositions (%) of *H. perforatum*, *H. hircinum* and *H. perfoliatum***

| Compound | Ki[a] | Ki[b] | *H. perforatum*[c] % | *H. hircinum* % | *H. perfoliatum* % | Identification[d] |
|---|---|---|---|---|---|---|
| *n*-Octane | 801 | 804 | --- | 0.2 | 0.8 | 1, 2 |
| 2-Methyloctane | 860 | | 5.2 | --- | 0.2 | 1, 2 |
| *n*-Nonane | 903 | 908 | 1.0 | 10.2 | 9.4 | 1, 2 |
| α-Pinene | 938 | 1032 | 0.3 | 2.2 | 25.3 | 1, 2, 3 |
| Verbenene | 951 | 1753 | --- | --- | t | 1, 2 |
| Camphene | 953 | 1076 | ---- | 0.4 | 0.1 | 1, 2, 3 |
| 3-Methyl-nonane | 971 | 965 | ---- | 0.4 | 0.5 | 1, 2 |
| β-Pinene | 980 | 1118 | 2.8 | 4.3 | 2.0 | 1, 2, 3 |
| 6-Methyl-5-hepten-2-one | 984 | 1319 | ---- | ---- | t | 1, 2 |
| β-Myrcene | 993 | 1174 | 0.3 | 0.2 | 0.8 | 1, 2, 3 |
| *n*-Decane | 1000 | 1051 | 0.2 | --- | 0.3 | 1, 2, 3 |
| α-Terpinene | 1012 | 1188 | --- | --- | 0.1 | 1, 2, 3 |
| *p*-Cymene | 1025 | 1280 | 0.7 | 0.3 | 0.2 | 1, 2, 3 |
| Limonene | 1030 | 1203 | 0.4 | 5.1 | 0.5 | 1, 2, 3 |
| 1,8-Cineole | 1034 | 1213 | --- | --- | 3.9 | 1, 2 |
| *Z*-(β)-Ocimene | 1039 | 1246 | --- | --- | t | 1, 2 |
| (*E*)-β-Ocimene | 1049 | 1280 | 0.3 | 0.1 | t | 1, 2, 3 |
| Benzeneacetaldehyde | 1052 | | --- | 0.1 | ---- | 1, 2 |
| γ-Terpinene | 1057 | 1255 | --- | 0.1 | 0.2 | 1, 2, 3 |
| Terpinolene | 1086 | 1265 | --- | 0.2 | 0.1 | 1, 2 |
| *p*-Cymenene | 1092 | | 0.2 | --- | --- | 1, 2, 3 |
| 2-Nonanone | 1094 | 1428 | - | 0.1 | --- | 1, 2 |

**(Table 16) Contd….**

| Compound | Ki[a] | Ki[b] | *H. perforatum*[c] % | *H. hircinum* % | *H. perfoliatum* % | Identification[d] |
|---|---|---|---|---|---|---|
| Linalool | 1097 | 1553 | 0.6 | 0.1 | 0.1 | 1, 2, 3 |
| β-Fenchol | 1098 | 1120 | --- | 0.1 | t | 1, 2 |
| *n*-Undecane | 1100 | 1100 | 6.3 | 2.0 | 3.8 | 1, 2, 3 |
| *n*-Nonanale | 1105 | | --- | 0.3 | 0.1 | 1, 2, 3 |
| α-Campholene aldehyde | 1126 | | --- | 0.1 | --- | 1, 2 |
| Campholenal | 1128 | 1497 | 0.5 | --- | --- | 1, 2 |
| *trans*-Pinocarveol | 1138 | 1654 | 0.2 | 1.5 | 0.2 | 1, 2 |
| *trans*-Limonene oxide | 1139 | 1442 | --- | t | --- | 1, 2 |
| Camphor | 1145 | 1532 | --- | 0.2 | 0.1 | 1, 2, 3 |
| Pinocarvone | 1165 | 1587 | 0.1 | 0.3 | - | 1, 2 |
| Borneol | 1167 | 1719 | --- | 0.1 | t | 1, 2, 3 |
| *iso*-Nonanol | 1171 | | 0.3 | --- | --- | 1, 2 |
| Terpinen-4-ol | 1176 | 1611 | 0.4 | 0.2 | --- | 1, 2, 3 |
| *p*-Cimen-8-ol | 1185 | 1864 | 0.2 | --- | --- | |
| α-Terpineol | 1189 | 1706 | 0.3 | 1.2 | 0.4 | 1, 2, 3 |
| Myrtenal | 1193 | 1648 | --- | 1.7 | --- | 1, 2 |
| Myrtenol | 1196 | 1804 | 0.1 | 0.7 | --- | 1, 2 |
| *n*-Decanale | 1210 | | --- | 0.2 | 0.1 | 1, 2 |
| *trans*-Carveol | 1217 | 1845 | ---- | 0.6 | --- | 1, 2 |
| Verbenone | 1218 | 1717 | ---- | 0.5 | --- | 1, 2 |
| *cis*-Carveol | 1226 | 1878 | 0.5 | 0.3 | --- | 1, 2 |
| Carvone | 1241 | 1752 | 0.1 | 0.4 | --- | 1, 2, 3 |
| Geraniol | 1255 | 1857 | t | 0.5 | --- | 1, 2 |
| Anethole | 1262 | 1780 | 0.1 | --- | --- | 1, 2, 3 |
| 2-Methyldodecane | 1266 | | 0.1 | --- | --- | 1, 2 |
| Thymol | 1293 | 2198 | --- | --- | 15.8 | 1, 2, 3 |
| *n*-Tridecane | 1300 | 1312 | 1.1 | --- | --- | 1, 2 |
| α-Cubebene | 1352 | 1466 | 0.1 | --- | --- | 1, 2 |
| α-Longipinene | 1355 | | 0.2 | --- | 0.7 | 1, 2 |
| Cyclosativene | 1363 | 1492 | --- | --- | t | 1, 2 |
| α-Ylangene | 1372 | 1493 | --- | --- | t | 1, 2 |
| β-Patchoulene | 1377 | 1488 | --- | - | t | 1, 2 |
| α-Copaene | 1377 | 1497 | 0.3 | 0.5 | 1.0 | 1, 2 |
| Isoledene | 1382 | 1367 | --- | 0.2 | --- | 1, 2 |
| β-Bourbonene | 1385 | 1535 | 0.1 | 0.5 | 0.1 | 1, 2 |
| β-Elemene | 1387 | 1600 | 0.1 | --- | 0.2 | 1, 2 |

**(Table 16) Contd….**

| Compound | Ki[a] | Ki[b] | *H. perforatum*[c] % | *H. hircinum* % | *H. perfoliatum* % | Identification[d] |
|---|---|---|---|---|---|---|
| β-Maaliene | 1392 | 2161 | --- | 0.2 | --- | 1, 2 |
| α-Gurjunene | 1408 | 1529 | --- | 4.0 | 0.2 | 1, 2 |
| α-Caryophyllene | 1444 | 1680 | 0.3 | --- | --- | 1, 2 |
| β-Caryophyllene | 1418 | 1612 | 12.3 | 3.0 | 1.1 | 1, 2 |
| β-Copaene | 1426 | 1430 | 0.3 | --- | --- | 1, 2 |
| β-Gurjunene | 1432 | 1612 | 0.2 | 1.9 | t | 1, 2 |
| Aromadendrene | 1437 | 1628 | 0.8 | 0.1 | 0.6 | 1, 2 |
| α-Himachalene | 1440 | | 0.9 | --- | --- | 1, 2 |
| (*E*)-β-Farnesene | 1452 | 1673 | 7.0 | 1.3 | --- | 1, 2 |
| α-Humulene | 1455 | 1689 | 1.0 | 0.3 | 1.1 | 1, 2 |
| *allo*-Aromadendrene | 1463 | 1661 | --- | 0.8 | 0.5 | 1, 2 |
| *trans*-Cadina-1(6),4-diene | 1472 | | --- | 1.7 | --- | 1, 2 |
| γ-Gurjunene | 1473 | 1687 | --- | 0.2 | --- | 1, 2 |
| Dodecanol | 1474 | 1973 | 1.8 | --- | --- | |
| β-Selinene | 1475 | 1715 | 0.2 | 0.4 | --- | 1, 2 |
| Germacrene D | 1477 | 1726 | 17.1 | --- | 2.1 | 1, 2 |
| γ-Muurolene | 1478 | 1704 | 11.1 | 1.0 | 1.0 | 1, 2 |
| *E*-(β)-Ionone | 1482 | 1957 | --- | --- | 1.0 | 1, 2 |
| δ-Selinene | 1486 | | --- | 11.4 | --- | 1, 2 |
| *cis*-β-Guajene | 1490 | 1694 | --- | 27.5 | --- | 1, 2 |
| Viridiflorene | 1491 | 1695 | --- | --- | 1.0 | 1, 2 |
| Biciclogermacrene | 1492 | 1756 | 4.9 | --- | t | 1, 2 |
| α-Selinene | 1498 | 1744 | 1.0 | 0.4 | --- | 1, 2 |
| α-Muurolene | 1503 | 1740 | 0.6 | --- | 0.5 | 1, 2 |
| (*E*,*E*)-α-Farnesene | 1508 | 1758 | 0.2 | 0.7 | 0.2 | 1, 2 |
| γ-Cadinene | 1515 | 1776 | 0.6 | --- | 0.9 | 1, 2 |
| δ-Cadinene | 1526 | 1773 | 0.4 | 0.2 | 2.1 | 1, 2 |
| α-Cadinene | 1532 | 1745 | --- | --- | t | 1, 2 |
| (*Z*)-3-Exenil-benzoate | 1533 | | 0.4 | --- | --- | 1, 2 |
| Cadina-1,4-diene | 1538 | 1799 | --- | --- | t | 1, 2 |
| α-Calacorene | 1541 | 1941 | --- | --- | 0.4 | 1, 2 |
| Ledol | 1565 | 2057 | --- | --- | 0.4 | 1, 2 |
| β-Calacorene | 1566 | 1942 | --- | 0.1 | | 1, 2 |
| *trans*-Nerolidol | 1566 | 2050 | 0.7 | --- | 0.2 | 1, 2 |
| Spathulenol | 1578 | 2150 | 3.8 | --- | 1.4 | 1, 2 |
| Caryophyllene oxide | 1580 | 2008 | 0.4 | 3.2 | 2.1 | 1, 2 |

**(Table 16) Contd….**

| Compound | Ki[a] | Ki[b] | *H. perforatum*[c] % | *H. hircinum* % | *H. perfoliatum* % | Identification[d] |
|---|---|---|---|---|---|---|
| *iso*-Aromadendrene epoxide | 1590 | | --- | --- | 0.4 | 1, 2 |
| Viridiflorol | 1591 | 2104 | --- | 0.9 | --- | 1, 2 |
| *allo*-Aromadendrene oxide | 1595 | 2054 | --- | --- | 0.9 | 1, 2 |
| Humulene epoxide | 1605 | 2011 | 1.7 | --- | --- | 1, 2 |
| δ-Cadinol | 1618 | 2233 | - | --- | 0.1 | 1, 2 |
| 1-*epi*-Cubenol | 1625 | 2088 | 0.6 | --- | --- | 1, 2 |
| τ-Cadinol | 1640 | 2187 | --- | --- | 11.5 | 1, 2 |
| α-Muurolol | 1643 | 2233 | --- | --- | t | 1, 2 |
| Cubenol | 1644 | 2080 | --- | --- | 0.4 | 1, 2 |
| α-Cadinol | 1649 | 2255 | --- | --- | 0.9 | 1, 2 |
| α-Bisabolol | 1668 | 2219 | --- | --- | 0.2 | 1, 2 |
| *n*-Tetradecanol | 1676 | 2179 | 3.5 | --- | --- | 1, 2 |
| 8-Cedren-13-ol | 1687 | 2359 | ---- | --- | 0.2 | 1, 2 |
| Benzyl benzoate | 1767 | 2563 | 0.1 | --- | ---- | 1, 2 |
| *n*-Hexadecanol | 1879 | 2342 | 0.3 | --- | ---- | 1, 2 |
| *n*-Nonadecane | 1900 | 1900 | 0.2 | --- | ---- | 1, 2 |
| *epi*-Cubebol | 1900 | 1914 | ---- | --- | 0.3 | 1, 2 |
| **Total** | | | **96.5** | **93.7** | **98.7** | |

The analyses were carried out in triplicate; [a]: Kovats retention index on HP-5 MS column; [b]: Kovats retention index on HP Innowax; [c] --- = absent; t = trace, less than 0.05%; [d]: Identification based on: 1 = Kovats retention index, 2 = mass spectrum, 3 = coinjection with authentic compound.

**Table 17. Effects of Different doses of Essential oils of *H. perforatum, H. perfoliatum* and *H. hircinum* on Germination of *Raphanus sativus* and *Lepidium sativum*. The Data are Expressed as Mean of Three Replicates ± SD**

| ***Raphanus sativus*** | | | |
|---|---|---|---|
| **Germinated Seeds** | | | |
| | *H. perforatum* | *H. perfoliatum* | *H. hircinum* |
| **Control** | 9.3±1.0 | 9.3±1.0 | 9.3±1.0 |
| **0.06 µg/mL** | 10.0±0.0 | 8.7±0.6 | 7.0±1.5 |
| **0.125 µg/mL** | 9.7±0.6 | 8.0±1.0 | 7.0±2.0 |
| **0.25 µg/mL** | 9.0±1.0 | 9.3±1.2 | 7.9±1.5 |
| **0.625 µg/mL** | 9.7±0.6 | 9.0±1.0 | 9.0±2.0 |
| **1.25 µg/mL** | 9.3±0.6 | 9.7±0.6 | 7.9±3.0 |
| **2.5 µg/mL** | 8.7±0.6 | 9.3±1.5 | 7.5±1.0 |
| ***Lepidium sativum*** | | | |
| **Germinated Seeds** | | | |
| | *H. perforatum* | *H. perfoliatum* | *H. hircinum* |
| **Control** | 8.7±1.2 | 8.7±1.2 | 8.7±1.2 |
| **0.06 µg/mL** | 10.0±0.0 | 9.0±1.0 | 8.7±2.3 |

**(Table 17) Contd….**

| *Lepidium sativum* | | | |
|---|---|---|---|
| **Germinated Seeds** | | | |
| **0.125 µg/mL** | 9.7±0.6 | 9.7±0.6 | 9.0±1.0 |
| **0.25 µg/mL** | 10.0±0.0 | 9.3±0.6 | 10.0±0.0 |
| **0.625 µg/mL** | 10.0±0.0 | 8.9±0.6 | 8.0±2.0 |
| **1.25 µg/mL** | 10.0±0.0 | 10.0±0.0 | 8.0±1.0 |
| **2.5 µg/mL** | 10.0±0.0 | 9.7±0.6 | 7.7±0.6* |

The values, followed by * (*p < 0.05; **p < 0.01, ***p < 0.001), are statistically different according to the Student's *t* test.

**Table 18. Effects of Different Doses of Essential oils of *H. perforatum, H. perfoliatum* and *H. hircinum* on Radicle Elongation of *Raphanus sativus* and *Lepidium sativum*. The Data are Expressed as Mean of Three Replicates ± SD**

| *Raphanus sativus* | | | |
|---|---|---|---|
| **Radicle Length (cm ± SD)** | | | |
| | *H. perforatum* | *H. perfoliatum* | *H. hircinum* |
| **Control** | 9.0±4.6 | 9.0±4.6 | 9.0±4.6 |
| **0.06 µg/mL** | 8.4±4.7 | 8.3±4.0 | 5.4±0.2* |
| **0.125 µg/mL** | 9.4±4.7 | 10.4±4.7 | 7.2±0.2 |
| **0.25 µg/mL** | 7.9±4.5 | 9.2±4.0 | 7.2±0.2 |
| **0.625 µg/mL** | 6.8±3.6* | 5.3±3.3*** | 5.4±0.2* |
| **1.25 µg/mL** | 8.2±3.8 | 8.5±4.9 | 5.4±0.2* |
| **2.5 µg/mL** | 6.3±3.9* | 7.2±3.9 | 5.4±0.2* |
| *Lepidium sativum* | | | |
| **Radicle Length (cm ± SD)** | | | |
| | *H. perforatum* | *H. perfoliatum* | *H. hircinum* |
| **Control** | 7.5±2.8 | 7.5±2.8 | 7.5±2.8 |
| **0.06 µg/mL** | 8.3±3.2 | 7.2±3.1 | 8.1±1.1 |
| **0.125 µg/mL** | 7.1±3.2 | 7.1±3.0 | 7.8±0.9 |
| **0.25 µg/mL** | 6.2±3.0 | 7.3±2.6 | 7.8±1.1 |
| **0.625 µg/mL** | 7.6±2.3 | 7.2±2.9 | 7.8±1.2 |
| **1.25 µg/mL** | 7.4±2.7 | 7.5±2.8 | 8.2±1.0 |
| **2.5 µg/mL** | 7.3±3.1 | 5.8±3.2* | 5.8±1.0* |

The values, followed by * (*p < 0.05; **p < 0.01, ***p < 0.001), are statistically different according to the Student's *t* test.

radicle elongation of radish and garden cress (Tables **22** and **23**). Generally, the germination of radish seeds is more affected by monoterpenes than garden cress seeds. In particular, at $10^{-3}$ M, a rather high concentration in the field of natural compounds, the substances provoked, in a significant way, inhibition on germination with this order of potency: geraniol > carvone > borneol > β-citronellol > α-terpineol > camphor > menthol > menthone > limonene > citral. Carvone and geraniol affected the germination of radish seeds with a 96% inhibition.

Menthone, limonene, carvone and camphor also inhibited, in a significant way, the germination of these seeds at $10^{-4}$ M. At the lowest doses assayed, the radish seeds were significantly inhibited only by 1,8-cineole. The germination of garden cress was less sensitive to inhibition by monoterpenes. In the matter of radicle elongation, monoterpenes affected both seeds, in a similar way. At $10^{-3}$ M, carvone, borneol, limonene and camphor were the most active compounds in inhibition of radish seedling growth, provoking an inhibition from 44% (camphor) to 79% (carvone). Carvone,

**Table 19. Essential Oil Composition (%) of *Helichrysum italicum* spp. *italicum***

| Compound | Ki[a] | Ki[b] | *Helichrysum italicum* spp. *italicum* % | Identification[c] |
|---|---|---|---|---|
| Menthol | 1165 | 1652 | 1.1 | 1,2,3 |
| Tetradecene | 1391 | 1433 | 0.7 | 1,2 |
| (*Z*)-Caryophyllene | 1408 | 1666 | 0.1 | 1,2 |
| Pentadecane | 1499 | 1500 | 0.9 | 1,2 |
| α-Bisabolene | 1504 | 1743 | 0.6 | 1,2 |
| *iso*-Italicene epoxide | 1510 | 2022 | 16.8 | 1,2 |
| *cis*-Cadinene ether | 1551 | | 0.5 | 1,2 |
| (*E*)-Nerolidol | 1565 | 2050 | 0.5 | 1,2 |
| Caryophyllenyl alcohol | 1568 | 2001 | 1.4 | 1,2 |
| *n*-Tridecanol | 1572 | 2077 | 1.4 | 1,2 |
| Neryl isovalerate | 1581 | 1871 | 0.5 | 1,2 |
| Caryophyllene oxide | 1585 | 2008 | 1.4 | 1,2 |
| Octanedioic acid, diethyl ester | 1588 | | 0.9 | 1,2 |
| Hexadecene | 1592 | 1654 | 9.8 | 1,2 |
| Guaiol | 1600 | 2108 | 2.3 | 1,2 |
| *cis*-Isolongifolanone | 1609 | | 1.4 | 1,2 |
| Isolongifolan-7-α-ol | 1615 | | 0.9 | 1,2 |
| 10-*epi*-γ-Eudesmol | 1617 | 2127 | 0.9 | 1,2 |
| (*Z*)-Bisabolol-11-ol | 1620 | | 1.4 | 1,2 |
| 1,10-di-*epi*-Cubenol | 1627 | 2250 | 2.3 | 1,2 |
| γ-Eudesmol | 1635 | 2185 | 1.4 | 1,2 |
| *allo*-Aromadedrene epoxide | 1641 | | 2.3 | 1,2 |
| β-Eudesmol | 1648 | 2258 | 1.4 | 1,2 |
| α-Eudesmol | 1655 | 2250 | 0.9 | 1,2 |
| 4α-H-Eudesm-11-en-4-ol | 1657 | 2274 | 1.4 | 1,2 |
| α-Betulenol | 1662 | | 1.8 | 1,2 |
| (*E*)-Bisabol-11-ol | 1668 | | 0.5 | 1,2 |
| 14-Hydroxy-9-*epi*-(*E*)-caryophyllene | 1670 | 2357 | 0.5 | 1,2 |
| β-Bisabolol | 1675 | 2170 | 0.5 | 1,2 |
| (*Z*)-Nerolidyl acetate | 1678 | | 2.3 | 1,2 |
| *epi*-α-Bisabolol | 1682 | 2400 | 0.9 | 1,2 |
| 8-Cedren-13-ol | 1688 | | 4.2 | 1,2 |
| (*Z*)-α-*trans*-Bergamotol | 1697 | 2247 | 4.7 | 1,2 |
| Selin-7(11)-en-4-ol | 1699 | 2273 | 1.4 | 1,2 |
| Amorpha-4,9-dien-14-al | 1704 | | 2.8 | 1,2 |
| Sesquiterpene | 1709 | | 1.4 | 1,2 |

**(Table 19) Contd….**

| Compound | Ki[a] | Ki[b] | *Helichrysum italicum* spp. *italicum* % | Identification[c] |
|---|---|---|---|---|
| (2*E*,6*Z*)-Farnesal | 1711 | | 1.4 | 1,2 |
| (*E*)-Nerolidyl acetate | 1717 | | 0.9 | 1,2 |
| Guaiol acetate | 1726 | | 0.5 | 1,2 |
| 6*S*,7*R*-Bisabolone | 1750 | | 2.3 | 1,2 |
| 2,6-Bisaboladien-12-ol | 1758 | 2580 | 2.3 | 1,2 |
| β-Costol | 1768 | 2606 | 7.5 | 1,2 |
| **Total** | | | **90.0** | |

The analyses were carried out in triplicate; [a]: Kovats retention index on HP-5 MS column; [b]: Kovats retention index on HP Innowax; [c]: Identification based on: 1 = Kovats retention index, 2 = mass spectrum, 3 = coinjection with authentic compound.

**Table 20. Effects of Different doses of Essential oil of *Helichrysum italicum* spp. *italicum* on Germination of *Raphanus sativus* and *Lepidium sativum*. The Data are Expressed as Mean of Three Replicates ± SD**

| ***Raphanus sativus*** | |
|---|---|
| **Germinated Seeds** | |
| | *Helichrysum italicum ssp. italicum* |
| **Control** | 9.3 ± 1.0 |
| **0.06 µg/mL** | 8.3 ± 0.6 |
| **0.125 µg/mL** | 9.3 ± 2.1 |
| **0.25 µg/mL** | 9.0 ± 1.0 |
| **0.625 µg/mL** | 8.0 ± 1.0 |
| **1.25 µg/mL** | 9.0 ± 0.0 |
| **2.5 µg/mL** | 9.7 ± 0.6 |
| ***Lepidium sativum*** | |
| **Germinated Seeds** | |
| **Control** | 8.7 ± 1.2 |
| **0.06 µg/mL** | 9.3 ± 1.2 |
| **0.125 µg/mL** | 9.7 ± 0.6 |
| **0.25 µg/mL** | 8.7 ± 0.6 |
| **0.625 µg/mL** | 9.7 ± 0.6 |
| **1.25 µg/mL** | 9.7 ± 0.6 |
| **2.5 µg/mL** | 8.7 ± 0.6 |

The values, followed by * (*$p < 0.05$; **$p < 0.01$, ***$p < 0.001$), are statistically different according to the Student's *t* test.

limonene and *p*-cymene inhibited the radicle elongation of garden cress also at $10^{-4}$ M. At $10^{-3}$ M, borneol, thymol, carvacrol, citronellol and camphor affected the radicle growth of garden cress, in a significant way; carvone inhibited significantly the seedling growth of these seeds both at $10^{-3}$ M and $10^{-4}$ M; also at $10^{-6}$ M, this compound provoked a 36% inhibition of seedling growth. As well as for the radish, at the lowest concentrations, 1,8-cineole inhibited, in a significant way, the primary root growth.

Alcohols (borneol, citronellol, geraniol, α-terpineol) appeared as the most inhibitory compounds ($10^{-3}$ M), followed by ketones (carvone, menthone, camphor) and aldehydes, against germination of tested seeds. Alcohols and ketones were the most inhibitory on both radish and garden cress

**Table 21. Effects of Different doses of Essential Oil of *Helichrysum italicum* spp. *italicum* on Radicle Elongation of *Raphanus sativus* and *Lepidium sativum*. The Data are Expressed as Mean of Three Replicates ± SD**

| ***Raphanus sativus*** | |
|---|---|
| **Radicle Length (cm ± SD)** | |
| | *Helichrysum italicum ssp. italicum* |
| **Control** | 9.0 ± 4.6 |
| **0.06 µg/mL** | 8.4 ± 4.1 |
| **0.125 µg/mL** | 8.6 ± 4.0 |
| **0.25 µg/mL** | 6.6 ± 4.7 * |
| **0.625 µg/mL** | 7.6 ± 3.7 |
| **1.25 µg/mL** | 6.5 ± 3.3 * |
| **2.5 µg/mL** | 6.4 ± 3.5 ** |
| ***Lepidium sativum*** | |
| **Radicle Length (cm ± SD)** | |
| | *Helichrysum italicum ssp. italicum* |
| **Control** | 7.5 ± 2.8 |
| **0.06 µg/mL** | 7.0 ± 2.5 |
| **0.125 µg/mL** | 6.5 ± 3.3 |
| **0.25 µg/mL** | 6.7 ± 3.0 |
| **0.625 µg/mL** | 6.2 ± 3.3 |
| **1.25 µg/mL** | 6.4 ± 1.6 |
| **2.5 µg/mL** | 6.2 ± 2.6 |

The values, followed by * (*p < 0.05; **p < 0.01, ***p < 0.001), are statistically different according to the Student's *t* test.

**Table 22. Effects of Different Concentrations of Monoterpenes on Germination of *Raphanus sativus* and *Lepidium sativum*. The Data are Expressed as Mean of Three Replicates ± SD**

| | ***Raphanus sativus*** | | | | ***Lepidium sativum*** | | | |
|---|---|---|---|---|---|---|---|---|
| | **Germinated Seeds** | | | | **Germinated Seeds** | | | |
| | **[$10^{-6}$] M** | **[$10^{-5}$] M** | **[$10^{-4}$] M** | **[$10^{-3}$] M** | **[$10^{-6}$] M** | **[$10^{-5}$] M** | **[$10^{-4}$] M** | **[$10^{-3}$] M** |
| **Control** | 12.4 ± 1.4 | 12.4 ± 1.4 | 12.4 ± 1.4 | 12.4 ± 1.4 | 14.4 ± 0.5 | 14.4 ± 0.5 | 14.4 ± 0.5 | 14.4 ± 0.5 |
| **(-)-Borneol** | 10.0 ± 0.0 | 10.5 ± 2.1 | 12.5 ± 2.1 | 2.0 ± 0.0*** | 14.0 ± 1.4 | 13.5 ± 0.7 | 13.5 ± 0.7 | 13.5 ± 0.7 |
| **(±)-Camphor** | 13.5 ± 2.1 | 13.0 ± 0.0 | 9.0 ± 1.4* | 6.0 ± 1.4** | 15.0 ± 0.0 | 12.5 ± 0.7** | 13.5 ± 0.7 | 13.0 ± 1.4* |
| **(±)-Citronellal** | 11.5 ± 0.7 | 10.5 ± 0.7 | 13.0 ± 1.4 | 11.0 ± 1.4 | 14.5 ± 0.7 | 14.0 ± 1.4 | 15.0 ± 0.0 | 15.0 ± 0.0 |
| **(±)-Menthol** | 11.0 ± 4.2 | 11.5 ± 2.1 | 11.0 ± 2.8 | 6.5 ± 2.1** | 13.5 ± 0.7 | 13.5 ± 2.1 | 14.5 ± 0.7 | 14.0 ± 1.4 |
| **(±)-β-Citronellol** | 10.5 ± 0.7 | 10.0 ± 1.4 | 13.0 ± 1.4 | 3.5 ± 2.1*** | 15.0 ± 0.0 | 14.0 ± 1.4 | 15.0 ± 0.0 | 13.0 ± 1.4 |
| **(R)-(-)Carvone** | 10.5 ± 0.7 | 9.0 ± 2.8 | 8.0 ± 2.8* | 0.5 ± 0.7*** | 14.5 ± 0.7 | 13.5 ± 0.7 | 14.5 ± 0.7 | 9.5 ± 2.1*** |
| **1,8-Cineole** | 9.5 ± 0.7 | 12.5 ± 0.7 | 10.5 ± 0.7 | 11.0 ± 2.8 | 14.0 ± 1.4 | 14.0 ± 1.4 | 13.5 ± 0.7 | 14.0 ± 1.4 |
| **Camphene** | 10.0 ± 2.8 | 11.5 ± 2.1 | 11.5 ± 0.7 | 13.5 ± 2.1 | 13.5 ± 0.7 | 13.5 ± 0.7 | 13.0 ± 1.4 | 13.5 ± 0.7 |
| **Carvacrol** | 11.5 ± 3.5 | 12.5 ± 2.1 | 13.0 ± 1.4 | 10.5 ± 0.7 | 14.0 ± 1.4 | 15.0 ± 0.0 | 14.0 ± 0.0 | 13.5 ± 0.7 |

**(Table 22) Contd….**

| | *Raphanus sativus* | | | | *Lepidium sativum* | | | |
|---|---|---|---|---|---|---|---|---|
| | Germinated Seeds | | | | Germinated Seeds | | | |
| | [$10^{-6}$] M | [$10^{-5}$] M | [$10^{-4}$] M | [$10^{-3}$] M | [$10^{-6}$] M | [$10^{-5}$] M | [$10^{-4}$] M | [$10^{-3}$] M |
| **Citral** | 11.5 ± 0.7 | 11.0 ± 1.4 | 12.5 ± 0.7 | 8.0 ± 1.4* | 15.0 ± 0.0 | 15.0 ± 0.0 | 14.5 ± 0.7 | 15.0 ± 0.0 |
| **Estragole** | 12.5 ± 0.7 | 12.0 ± 2.8 | 12.5 ± 0.7 | 11.5 ± 2.1 | 12.5 ± 2.1 | 15.0 ± 0.0 | 14.0 ± 1.4 | 15.0 ± 0.0 |
| **Geraniol** | 9.5 ± 0.7 | 12.5 ± 0.7 | 10.0 ± 0.0 | 0.5 ± 0.7*** | 14.5 ± 0.7 | 15.0 ± 0.0 | 15.0 ± 0.0 | 6.0 ± 1.4*** |
| **Geranyl acetate** | 10.5 ± 0.7 | 11.5 ± 0.7 | 11.0 ± 0.0 | 9.5 ± 2.1 | 13.5 ± 2.1 | 14.5 ± 0.7 | 14.5 ± 0.7 | 13.5 ± 0.7 |
| **Limonene** | 11.5 ± 2.1 | 8.5 ± 4.9 | 8.0 ± 2.8* | 7.0 ± 1.4** | 13.0 ± 1.4* | 14.5 ± 0.7 | 15.0 ± 0.0 | 11.5 ± 3.5* |
| **Linalool** | 12.0 ± 2.8 | 9.5 ± 2.1 | 10.5 ± 2.1 | 10.0 ± 1.4 | 14.5 ± 0.7 | 13.0 ± 1.4 | 13.5 ± 0.7 | 14.0 ± 0.0 |
| **Linalyl acetate** | 13.0 ± 0.0 | 11.5 ± 3.5 | 12.5 ± 0.7 | 11.0 ± 1.4 | 14.0 ± 1.4 | 15.0 ± 0.0 | 14.0 ± 0.0 | 15.0 ± 0.0 |
| **Menthone** | 10.0 ± 0.0 | 11.0 ± 1.4 | 7.0 ± 1.4** | 6.5 ± 2.1** | 13.5 ± 2.1 | 13.5 ± 0.7 | 14.0 ± 1.4 | 13.5 ± 0.7 |
| **Myrcene** | 13.0 ± 1.4 | 14.0 ± 1.4 | 14.0 ± 1.4 | 14.0 ± 0.0 | 14.0 ± 0.0 | 14.5 ± 0.7 | 14.5 ± 0.7 | 14.5 ± 0.7 |
| ***p*-Cymene** | 13.0 ± 2.8 | 10.5 ± 2.1 | 11.5 ± 2.1 | 13.0 ± 1.4 | 14.0 ± 0.0 | 14.0 ± 0.0 | 13.5 ± 2.1 | 13.5 ± 0.7 |
| **Thymol** | 11.5 ± 2.1 | 13.5 ± 0.7 | 12.0 ± 1.4 | 10.5 ± 0.7 | 15.0 ± 0.0 | 15.0 ± 0.0 | 15.0 ± 0.0 | 7.0 ± 1.4 |
| **α-Phellandrene** | 11.0 ± 0.0 | 12.5 ± 0.7 | 11.5 ± 2.1 | 13.0 ± 0.0 | 15.0 ± 0.0 | 14.5 ± 0.7 | 15.0 ± 0.0 | 14.0 ± 0.0 |
| **α-Pinene** | 13.0 ± 1.4 | 13.0 ± 1.4 | 11.5 ± 0.7 | 12.5 ± 0.7 | 15.0 ± 0.0 | 14.5 ± 0.7 | 15.0 ± 0.0 | 14.5 ± 0.7 |
| **α-Terpinene** | 13.0 ± 2.8 | 12.0 ± 0.0 | 13.0 ± 0.0 | 13.0 ± 0.0 | 15.0 ± 0.0 | 14.5 ± 0.7 | 14.5 ± 0.7 | 15.0 ± 0.0 |
| **α-Terpineol** | 12.5 ± 2.1 | 13.5 ± 2.1 | 14.0 ± 0.0 | 5.0 ± 0.0*** | 15.0 ± 0.0 | 15.0 ± 0.0 | 15.0 ± 0.0 | 14.5 ± 0.7 |
| **α-β Thujone** | 12.0 ± 0.0 | 12.0 ± 1.4 | 12.0 ± 1.4 | 10.0 ± 0.0 | 15.0 ± 0.0 | 15.0 ± 0.0 | 15.0 ± 0.0 | 15.0 ± 0.0 |
| **β-Pinene** | 13.5 ± 2.1 | 13.0 ± 1.4 | 11.0 ± 0.0 | 12.0 ± 0.0 | 15.0 ± 0.0 | 15.0 ± 0.0 | 15.0 ± 0.0 | 15.0 ± 0.0 |
| **γ-Terpinene** | 11.0 ± 1.4 | 14.0 ± 1.4 | 14.5 ± 0.7 | 14.0 ± 0.0 | 15.0 ± 0.0 | 14.5 ± 0.7 | 14.5 ± 0.7 | 14.5 ± 0.7 |

The values, followed by * (*$p < 0.05$; ** $p < 0.01$, *** $p < 0.001$), are statistically different according to the Student's *t* test.

radicle growth. On the whole, different degrees of inhibition were observed when compared with control groups, whereas oxygenated monoterpenes have more potent herbicidal effects on seed germination as compared with monoterpene hydrocarbons. As shown in Tables **22** and **23**, monoterpene hydrocarbons have less or no phytotoxic effects on the seed germination of two seeds. Moreover, alcohol derivatives of oxygenated monoterpenes were more phytotoxic than their acetate derivatives. In some cases, monoterpenes did not affect radicle elongation of two seeds assayed, but they inhibited only seed germination: in fact, geraniol, α-terpineol, menthone, menthol, citral, at the highest concentrations tested, inhibited significantly germination of seeds. On the other hand, carvacrol, thymol, *p*-cymene and 1,8-cineole inhibited the seedling growth of the seeds, but they did not affect their germination.

In several cases, some doses of the same oil are inhibitory, other stimulatory. The concept of a generalized "low-dose stimulation–high dose inhibition" or "hormesis" was gradually supported by field observations [30]. There is evidence that exposure to novel environments or a toxic substance increases the variance of phenotypic traits such as enzyme activity, morphological features and growth. However, the reasons for such increases and their adaptive implications remain unclear [27]. Our data agree with the literature on inhibitory activity exerted by essential oils of Mediterranean species on seed germination and radical elongation and in general on vegetation pattern. It has been documented that some essential oils isolated possess potent herbicidal effects on weed germination and seedling growth of various plant species [16, 31-34].

Dudai and coworkers [35] reported that monoterpenes act on seeds at very low levels, and that their content in various parts of wheat seeds differs. In particular, among the Lamiaceae family, many species release phytotoxic monoterpenes that hinder the development of herbaceous species among which β-pinene, limonene, *p*-cymene, 1,8-cineole [16]. A dramatic example of zones free of annual herbs, influenced by terpenoids, was before demonstrated by Muller [12], in California chaparral, in the areas surrounding patches of *Salvia leucophylla* L. (Labiatae) and *Artemisia californica* Lee. Volatile monoterpenoids emanating from leaves of *Salvia leucophylla* L. are responsible for anatomical and physiological changes occurring in herb seedlings which were exposed to vapors [36]. The absence of a variety of intact organelles and the presence of membrane fragments indicate that structural breakdown and decomposition occur within inhibited roots [37].

**Table 23. Effects of Different Concentrations of Monoterpenes on Radical Elongation of *Raphanus sativus* and *Lepidium sativum*. The Data are Expressed as Mean of Three Replicates ± SD**

| | *Raphanus sativus* | | | | *lepidium sativum* | | | |
|---|---|---|---|---|---|---|---|---|
| | Radicle Length (cm ± SD) | | | | Radicle Length (cm ± SD) | | | |
| | $[10^{-6}]$ M | $[10^{-5}]$ M | $[10^{-4}]$ M | $[10^{-3}]$ M | $[10^{-6}]$ M | $[10^{-5}]$ M | $[10^{-4}]$ M | $[10^{-3}]$ M |
| **Control** | 1.8 ± 0.4 | 1.8 ± 0.4 | 1.8 ± 0.4 | 1.8 ± 0.4 | 1.9 ± 0.2 | 1.9 ± 0.2 | 1.9 ± 0.2 | 1.9 ± 0.2 |
| **(-)-Borneol** | 1.6 ± 0.8 | 1.6 ± 1.1 | 1.9 ± 1.1 | 0.5 ± 0.1** | 1.3 ± 0.7 | 1.1 ± 0.6* | 1.6 ± 0.7 | 0.2 ± 0.1*** |
| **(±)-Camphor** | 1.6 ± 1.0 | 2.1 ± 0.9 | 1.2 ± 0.8 | 1.0 ± 0.5* | 1.6 ± 0.9 | 1.7 ± 0.7 | 1.5 ± 0.6 | 1.1 ± 0.5** |
| **(±)-Citronellal** | 1.8 ± 1.1 | 1.5 ± 0.8 | 2.0 ± 1.2 | 1.7 ± 1.4 | 2.1 ± 0.6 | 2.0 ± 0.7 | 2.0 ± 0.7 | 1.8 ± 0.7 |
| **(±)-Menthol** | 1.9 ± 0.7 | 1.9 ± 0.8 | 1.7 ± 1.0 | 1.5 ± 0.8 | 1.6 ± 1.0 | 1.9 ± 0.7 | 1.8 ± 0.9 | 1.4 ± 0.6 |
| **(±)-β-Citronellol** | 1.5 ± 0.9 | 1.4 ± 0.7 | 1.4 ± 0.7 | 1.1 ± 0.8 | 2.0 ± 1.2 | 1.6 ± 0.8 | 1.7 ± 0.6 | 0.7 ± 0.5*** |
| **(R)-(-)Carvone** | 1.0 ± 0.5** | 1.4 ± 0.8 | 0.9 ± 0.5** | 0.1 ± 0.1*** | 1.3 ± 0.6* | 1.2 ± 0.7 | 0.8 ± 0.4*** | 0.4 ± 0.2*** |
| **1,8-Cineole** | 0.9 ± 0.5** | 0.9 ± 0.6** | 1.1 ± 0.8 | 1.2 ± 0.7 | 1.2 ± 0.5** | 1.2 ± 0.6* | 1.5 ± 0.8 | 1.8 ± 1.0 |
| **Camphene** | 1.6 ± 0.8 | 1.6 ± 1.2 | 1.5 ± 0.7 | 1.2 ± 0.8 | 1.3 ± 0.7 | 2.1 ± 0.9 | 1.7 ± 0.8 | 1.9 ± 0.9 |
| **Carvacrol** | 2.2 ± 1.6 | 2.0 ± 1.3 | 2.0 ± 1.3 | 1.8 ± 1.0 | 2.1 ± 0.7 | 1.8 ± 0.8 | 1.7 ± 0.8 | 0.6 ± 0.3*** |
| **Citral** | 1.3 ± 0.4* | 2.3 ± 1.3 | 2.1 ± 1.1 | 1.3 ± 0.8 | 1.7 ± 0.7 | 1.7 ± 0.9 | 1.9 ± 0.7 | 1.4 ± 0.6 |
| **Estragole** | 1.3 ± 0.7 | 1.4 ± 0.9 | 1.3 ± 0.9 | 1.3 ± 0.8 | 1.5 ± 1.0 | 1.6 ± 0.8 | 1.3 ± 0.6 | 1.3 ± 0.9 |
| **Geraniol** | 1.4 ± 0.7 | 1.8 ± 0.9 | 1.7 ± 0.9 | 0.3 ± 0.5 | 2.1 ± 0.6 | 1.5 ± 0.7 | 1.6 ± 0.8 | 0.8 ± 0.4 |
| **Geranyl acetate** | 1.4 ± 0.8 | 1.4 ± 0.8 | 1.3 ± 0.5 | 1.2 ± 0.4 | 1.8 ± 0.7 | 1.3 ± 0.7 | 1.6 ± 0.8 | 1.5 ± 0.7 |
| **Limonene** | 1.4 ± 0.7 | 1.9 ± 1.1 | 0.9 ± 0.5** | 0.9 ± 0.4** | 1.2 ± 0.8 | 1.5 ± 0.6 | 1.3 ± 0.9 | 1.8 ± 0.8 |
| **Linalool** | 1.4 ± 0.6 | 1.2 ± 0.7 | 1.5 ± 0.7 | 1.4 ± 1.1 | 1.7 ± 0.8 | 1.4 ± 0.7 | 2.0 ± 0.9 | 1.6 ± 0.7 |
| **Linalyl acetate** | 1.5 ± 0.7 | 1.6 ± 0.8 | 1.6 ± 1.0 | 1.1 ± 0.6 | 1.4 ± 0.6 | 1.9 ± 0.7 | 1.4 ± 0.6 | 1.7 ± 0.6 |
| **Menthone** | 1.6 ± 0.8 | 1.4 ± 0.7 | 1.4 ± 0.6 | 1.2 ± 0.6 | 1.8 ± 1.0 | 2.4 ± 0.9 | 1.6 ± 0.8 | 1.4 ± 0.8 |
| **Myrcene** | 1.7 ± 1.2 | 1.9 ± 1.2 | 2.4 ± 1.8 | 2.5 ± 1.6 | 2.0 ± 0.6 | 1.6 ± 0.6 | 2.0 ± 0.8 | 1.8 ± 0.6 |
| ***p*-Cymene** | 1.5 ± 0.8 | 1.3 ± 0.6 | 1.1 ± 0.6* | 1.7 ± 0.9 | 2.6 ± 1.1 | 1.9 ± 0.9 | 1.7 ± 0.7 | 2.3 ± 0.8 |
| **Thymol** | 1.7 ± 0.9 | 2.5 ± 1.4 | 2.1 ± 1.3 | 1.5 ± 0.9 | 1.9 ± 0.8 | 2.1 ± 0.7 | 1.9 ± 1.1 | 0.5 ± 0.1*** |
| **α-Phellandrene** | 1.4 ± 0.8 | 1.4 ± 0.8 | 2.0 ± 1.2 | 1.7 ± 0.8 | 2.2 ± 0.8 | 2.0 ± 0.8 | 1.8 ± 1.0 | 1.8 ± 1.0 |
| **α-Pinene** | 1.4 ± 0.8 | 1.7 ± 0.7 | 1.5 ± 0.8 | 1.4 ± 0.9 | 2.2 ± 0.9 | 1.6 ± 0.6 | 1.6 ± 0.7 | 1.6 ± 0.6 |
| **α-Terpinene** | 1.9 ± 1.3 | 1.7 ± 1.4 | 1.9 ± 1.4 | 1.5 ± 0.6 | 2.0 ± 1.0 | 1.8 ± 0.7 | 2.0 ± 0.6 | 1.9 ± 0.8 |
| **α-Terpineol** | 2.0 ± 1.2 | 2.0 ± 1.7 | 2.3 ± 1.3 | 2.1 ± 1.0 | 1.7 ± 0.7 | 2.2 ± 0.6 | 2.2 ± 0.5 | 1.7 ± 0.5 |
| **α-β Thujone** | 1.7 ± 0.9 | 1.6 ± 1.2 | 1.8 ± 1.1 | 1.5 ± 1.3 | 2.2 ± 0.9 | 1.8 ± 0.9 | 1.9 ± 0.9 | 1.7 ± 0.6 |
| **β-Pinene** | 1.4 ± 0.8 | 1.3 ± 0.6 | 1.5 ± 0.9 | 1.3 ± 0.6 | 1.8 ± 0.8 | 1.7 ± 0.8 | 2.0 ± 0.8 | 2.0 ± 0.8 |
| **γ-Terpinene** | 1.9 ± 1.4 | 1.7 ± 1.3 | 2.2 ± 1.3 | 1.7 ± 1.2 | 2.0 ± 0.8 | 1.7 ± 0.5 | 1.9 ± 0.9 | 1.6 ± 0.5 |

The values followed by * (* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$), are statistically different according to the Student's *t* test.

A lot of studies showed that essential oils isolated from various plant species, on the whole, and specifically monoterpenes, exert potent herbicidal effects on weed germination and primary root growth of several other species [16, 38-41].

Although the mechanisms of essential oil action against germination is still unclear, it reported that volatile oils, monoterpenoids and also sesquiterpenoids inhibit cell division and induce structural breaks and decomposition in roots [23, 40]. In agreement with our results, several Authors [38, 42] previously reported that 1,8-cineole and camphor have strong phytotoxic effects against various plant species; citronellal, citronellol, linalool [43, 44], α-pinene [38, 44] and limonene [38] are known as high inhibitors of seed germina-

tion and seedling growth. Monoterpenes have been reported for their effects on mitochondrial respiration [45] and for disruption of cellular membranes [46]. A structure-activity relationship for some monoterpenes has been proposed by Asplund [47, 48]. Both monoterpenoids and sesquiterpenoids appear to be involved in phytotoxic effects: infact, sesquiterpenoid compounds, as β-maaliene, α-isocomene, β-isocomene, δ-cadinene, 5-hydroxy-calamenene and 5-methoxycalamenene were recently shown to inhibit the seedling growth of associated native vegetation, and thus possibly help in successful invasion in the introduced sites [23, 49]. Moreover, in several papers, monoterpene hydrocarbons showed to posses lower inhibitory activity than oxygenated compounds [39, 42, 43]. Also in our study [24], some oxygenated monoterpenes showed high inhibitory activity on germination and radicle elongation of radish and garden cress seeds: it is well known that these compounds have phytotoxic effects that may cause anatomical and physiological changes in seedlings: reduction in some organelles such as mitochondria, accumulation of lipid globules in the cytoplasm, may be due to inhibition of DNA synthesis or disruption of membranes [40, 50]. Batish and coworkers [51] reported that the oil from *E. citriodora* inhibited root growth by suppressing of mitotic activity. Singh and coworkers [13] reported that the oil of *Artemisia scoparia* inhibited germination and plant root growth through generation of ROS-induced oxidative stress. Kordali and coworkers [42] reported that β-citronellol, nerol and terpinen 4-ol completely inhibited seed germination and seedling growth of tested plants. Similar results were found in our study. Moreover, our data showed that the tested alcohols, phenols and ketones were more active than others classes.

The different degrees of biological activity could be related to the composition of the essential oils: in particular, the presence of monoterpenoids [23] could explain the biological activity.

Generally, the roots were probably more sensitive than shoots to the phytotoxic activity of the oil: the process of germination was active while the oil probably affected the elongation process.

The effect of an essential oil on seed germination and seedling growth is often explained in terms of the individual effects of some main constituents. However, an essential oil is a mixture of many compounds in different proportions, and it is often not known whether and how they might interact synergistically. In addition, there is considerable variability in the composition of the essential oil of a certain plant species; this variability may be seasonal or infraspecific, between different populations of the same species, or even between individuals of the same population [39]: differences in the composition between our sample and those reported in literature can be explained by various factors, e.g., the harvest time, local, climatic, geographical, seasonal factors [52]. Generally, chemotypes can determine "biochemical varieties" or "physiological forms" in botanical species, each of which has a specific enzymatic equipment. These species are genetically codified and direct their biosynthesis to the preferential formation of a definite compound. 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 essences, environmental conditions are able to influence biosynthetic pathway. Given this variability, the overall effect of the essential oil of an aromatic plant cannot be predicted, unless we know both its exact composition and the type of interactions among its constituents.

Recently, 1,4-cineole, a natural analog of 1,8-cineole with lower occurrence, has been reported as a potent inhibitor of asparagines-synthetase [17]. The synthetical analogue of 1,4-cineole, cinmethylin, was use as commercial herbicide for its physiochemical properties (it was less volatile and more handy than 1,4-cineole).

In this perspective, the *in vitro* inhibition on radish and cress germination by the tested essential oils appears to be important, considering the possible use of the oils or their main constituents as potential bio-herbicides in development of sustainable agriculture practices and as lead structures for the development of new, potentially safe and ecocompatible pesticides. Further studies will be needed to investigate costs, selectivity, safety and mode of action of these monoterpenes.

## CONFLICT OF INTEREST

None.

## ACKNOWLEDGEMENT

None.

## REFERENCES

[1] Edris, A.E. Pharmaceutical and therapeutic potentials of essential oils and their individual volatile constituents: A review. *Phytother. Res.*, **2007**, *21*, 308-323.

[2] Bakkali, F.; Averbeck, S; Averbeck, D.; Idaomar M. Biological effects of essential oils - A review. *Food Chem. Toxicol.*, **2008**, *46*, 446-475.

[3] Rice, E.L. *Allelopathy*, 2nd ed.; Academic Press: New York, **1984**.

[4] Harborne J.B. *Introduction to Ecological Biochemistry*; Academic Press: London, UK, **1988**.

[5] Inderjit. Plant phenolics in allelopathy. *Bot. Rev.*, **1996**, *62*, 186-202.

[6] Seigler, D.S. Chemistry and mechanisms of allelopathic interactions. *Agron. J.*, **1996**, *88*, 876-885.

[7] Arminante, F.; De Falco, E.; De Feo, V.; De Martino, L.; Mancini, E.; Quaranta E. Allelophatic activity of essential oils from mediterranean Labiatae. *Acta Horticult.*, **2006**, *723*, 347-352.

[8] Muller, C.H. Inhibitory terpenes volatilized from *Salvia* shrubs. *Bull. Torrey Bot. Club*, **1964**, *92*, 38-45.

[9] Muller, W.H.; Muller, C.H. Volatile growth inhibitors produced by *Salvia* species. *Bull. Torrey Bot. Club*, **1964**, *91*, 327-330.

[10] Muller, C.H.; Muller, W.H.; Haines, B.L. Volatile growth inhibitors produced by aromatic shrubs. *Science*, **1964**, *143*, 471-473.

[11] Muller, W.H.; Lorber, P.; Haley, B. Volatile growth inhibitors produced by *Salvia leucophylla*: Effect on seedling growth and respiration. *Bull. Torrey Bot. Club*, **1968**, *95*, 415-522.

[12] Muller, W.H.; Lorber, P.; Haley, B.; Johnson, K. Volatile growth inhibitors produced by *Salvia leucophylla*: Effects on oxygen uptake by mitocondrial suspensios. *Bull. Torrey Bot. Club*, **1969**, *96*, 89-95.

[13] Singh, H.P.; Kaur, S.; Mittal, S.; Batish, D.R.; Kohli, R.K. Essential oil of *Artemisia scoparia* inhibits plant growth by generating reactive oxygen species and causing oxidative damage. *J. Chem. Ecol.*, **2009**, *35*, 154-162.

[14] Tellez, M.R.; Kobaisy, M.; Duke, S.O.; Schrader, K.K.; Dayan, F.E.; Romagni, J. Terpenoid based defense in plants and other organisms. In: *Lipid Technology*; Kuo, T.M., Gardner, H.W., Eds. Marcel Dekker: New York, NY, USA, **2002**; p. 354.

[15] Duke, S.O.; Dayan, F.E.; Romagni, J.G.; Rimando, A.M. Natural products as sources of herbicides: current status and future trends. *Weed Res*., **2000**, *40*, 99-111.

[16] Angelini, L.G.; Carpanese, G.; Cioni, P.L.; Morelli, I.; Macchia, M.; Flamini, G. Essential oils from Mediterranean Lamiaceae as weed germination inhibitors. *J. Agric. Food Chem.*, **2003**, *51*, 6158-6164.

[17] Duke, S.O.; Oliva, A. Mode of action of phytotoxic terpenoids. In: *Allelopathy. Chemistry and Mode of Action of Allelochemicals*; Macias, F.A., Galindo, J.C.G., Molinillo, J.M.G., Cutler, H.G., Eds. CRC Press: Boca Raton, FL, USA, **2004**; pp. 201-206.

[18] Azirak, S. & Karaman, S. Allelopathic effect of some essential oils and components on germination of weed species. *Acta Agric. Scand. Sect. B*, **2008**, *58*, 88-92.

[19] Vokou, D. The Allelophatic potential of aromatic shrubs in phryganic (East Mediterranean) ecosystems. In: *Allelopathy: Basic and Applied Aspects*; Rizvi, S.J.H., Rizvi, V., Eds.; Chapman & Hale: London, UK, **1992**; pp. 303-320.

[20] Vokou, D.; Margaris, N.S. Variation of volatile oil concentration of Mediterranean aromatic shrubs *Thymus capitatus* Hoffmagg et Link, *Satureja thymbra* L., *Teucrium polium* L., and *Rosmarinus officinalis. Int. J. Biometeorol.*, **1986**, *30*, 147-155.

[21] Mancini, E.; Arnold, N.A.; De Feo, V.; Formisano, C.; Rigano, D.; Piozzi, F.; Senatore, F. Phytotoxic effects of essential oils of *Nepeta curviflora* Boiss. and *Nepeta nuda* L. subsp. *albiflora* growing wild in Lebanon. *J. Plant Intercat.*, **2009**, *4*(4), 253-259.

[22] Mancini, E.; Arnold, N.A.; De Martino, L.; De Feo, V.; Formisano, C.; Rigano, D.; Senatore, F. Chemical composition and phytotoxic effects of essential oils of *Salvia hierosolymitana* Boiss. and *Salvia multicaulis* Vahl. var. *simplicifolia* Boiss. Growing wild in Lebanon. *Molecules*, **2009**, *14*, 4725-4736.

[23] De Martino, L.; Roscigno, G.; Mancini, E.; De Falco, E.; De Feo, V. Chemical composition and antigerminative activity of the essential oils from five *Salvia* species. *Molecules*, **2010**, *15*(2), 735-746.

[24] De Martino, L.; Mancini, E.; Rolim de Almeida, L.F.; De Feo, V. The antigerminative activity of twenty-seven monoterpenes. *Molecules*, **2010**, *15*, 6630-6637

[25] De Martino, L.; Roscigno, G.; Mancini, E., De Falco, E.; De Feo V. Chemical composition and antigerminative activity of the essential oils from five *Salvia* species. *Molecules*, **2010**, *15*, 735-746.

[26] De Martino, L.; Formisano, C.; Mancini, E.; De Feo, V.; Piozzi, F.; Rigano, D.; Senatore, F. Chemical composition and phytotoxic effects of essential oils from four *Teucrium* species. *Nat. Prod. Commun.*, **2010**, *5*(12), 1969-1976

[27] Rolim de Almeida, L.F.; Frei, F.; Mancini, E.; De Martino, L.; De Feo, V. Phytotoxic activities of Mediterranean essential oils. *Molecules*, **2010**, *15*, 4309-4323

[28] Mancini, E.; De Martino, L.; Marandino, A.; Scognamiglio, M. R.; De Feo, V. Chemical Composition and Possible *in vitro* Phytotoxic Activity of *Helichrsyum italicum* (Roth) Don ssp. *Italicum*. *Molecules*, **2011**, *16*, 7725-7735.

[29] Marandino, A.; De Martino, L.; Mancini, E.; Milella, L.; De Feo, V. Chemical composition and possible *in vitro* antigermination activity of three *Hypericum* essential oils. *Nat. Prod. Commun.*, **2011**, *6*(11), 1735-1738.

[30] Stebbing, A.R.D. Hormesis-the stimulation of growth by low levels of inhibitors. *Sci. Total Environ.*, **1982**, *22*, 213-234.

[31] Dudai, N.; Poljakoff-Mayber, A.; Mayer, A.M.; Putievsky, E.; Lerner, H.R. Essential oils as allelochemicals and their potential use as bioherbicides. *J. Chem. Ecol.*, **1999**, *25*, 1079-1089.

[32] Tworkoski, T. Herbicide effects of essential oils. *Weed Sci.*, **2002**, *50*, 425-431.

[33] Isman, M.B.; Machial, C.M.; Miresmailli, S.; Bainard, L.D. Essential oil-based pesticides: new insights from old chemistry. In: Pesticide Chemistry; Ohkawa, H.; Miyagawa, H.; Lee, P.; Eds. Wiley-VCH, Weinheim, **2007**; pp. 201-209.

[34] Kordali, S.; Cakir, A.; Ozer, H.; Cakmakci, R.; Kesdek, M.; Mete, E. Antifungal, phytotoxic and insecticidal properties of essential oil isolated fromTurkish *Origanum acutidens* and its three components, carvacrol, thymol and *p*-cymene. *Bioresour. Technol.*, **2008**, *99*, 8788-8795.

[35] Dudai, N.; Larkov, O.; Putievsky, E.; Lerner, H.R.; Ravid, U.; Lewinsohn, E.; Mayer, A.M. Biotransformation of constituents of essential oils by germinating wheat seed. *Phytochemistry*, **2000**, *55*, 375-382.

[36] Lorber, P.; Muller, W.H. Volatile growth inhibitors produced by *Salvia leucophylla*: Effects on seedling root tip ultrastructure. *Am. J. Bot.*, **1976**, *63*, 196-200.

[37] Scrivanti, L.R.; Zunino, M.P.; Zygadlo, J.A. *Tagetes minuta* and *Schinus areira* essential oils as allelopathic agents. *Biochem. Syst. Ecol.*, **2003**, *31*, 563-572.

[38] Abrahim, D.; Braguini, W.L.; Kelmer-Bracht, A.M.; Ishii-Iwamoto, E.L. Effects of four monoterpenes on germination, primary root growth, and mitochondrial respiration of maize. *J. Chem. Ecol.*, **2000**, *26*, 611-624.

[39] Vokou, D.; Douvli, P.; Blionis, G.J.; Halley, J.M. Effects of monoterpenoids, acting alone or in pairs, on seed germination and subsequent seedling growth. *J. Chem. Ecol.*, **2003**, *29*, 2281-2301.

[40] Nishida, N.; Tamotsu, S.; Nagata, N.; Saito, C.; Sakai, A. Allelopathic effects of volatile monoterpenoids produced by *Salvia leucophylla*: inhibition of cell proliferation and DNA synthesis in the root apical meristem of *Brassica campestris* seedlings. *J. Chem. Ecol.*, **2005**, *31*, 1187-1203.

[41] Salamci, E.; Kordali, S.; Kotan, R.; Cakir, A.; Kaja, Y. Chemical composition, antimicrobial and herbicidal effects of essential oils isolated Turkish *Tanacetum aucheranum* and *Tanacetum chiliophyllum* var. *chiliophyllum. Biochem. Syst. Ecol*., **2007**, *35*, 569-581.

[42] Kordali, S.; Cakir, A.; Sutay, S. Inhibitory effects of monoterpenes on seed germination and seedling growth. *Z. Naturforsch. C*, **2007**, *62*, 207-214.

[43] Singh, H.P.; Batish, D.R.; Kaur, S.; Ramezani, H.; Kohli, R.K. Comparative phytotoxicity of four monoterpenes against *Cassia occidentalis*. *Ann. Appl. Biol*., **2002**, *141*, 111-116.

[44] Singh, H.P.; Batish, D.R.; Kaur, S.; Arora, K.; Kohli R.K. *α*-pinene inhibits growth and induces oxidative stress in roots. *Ann. Bot.*, **2006**, *98*, 1261-1269.

[45] Abrahim, D.; Francischini, A.D., Pergo, E.M., Kelmer-Bracht, A.M.; Ishii-Iwamoto, E.L. Effect of α-pinene on the mitochondrial respiration of maize seedlings. *Plant Physiol. Biochem*., **2003**, *41*, 985-991.

[46] Lorber, P.; Muller, W.H.. Volatile growth inhibitors produced by *Salvia leucophylla*: effects on cytological activity in mitochondrial suspensions. *Comp. Physiol. Ecol*., **1980**, *5*, 68-75.

[47] Asplund, R.O. Monoterpenes; relation between structure and inhibition of germination. *Phytochemistry*, **1968**, *7*, 1995-1997.

[48] Asplund, R.O. Quantitative aspects of the phytotoxicity of monoterpenes. *Weed Sci.*, **1969**, *17*, 454-455.

[49] Ens, E.J.; Bremner, J.B.; French, K.; Korth, J. Identification of volatile compounds released by roots of an invasive plant, bitou bush (*Chrysanthemoides monilifera* spp. *rotundata*), and their inhibition of native seedling growth. *Biol. Invasions*, **2008**, *11*, 275-287.

[50] Zunino, M.P.; Zygadlo J.A. Effect of monoterpenes on lipid oxidation in maize. *Planta*, **2004**, *219*, 303-309.

[51] Batish, D.R.; Lavanya, K.; Singh, H.P.; Kohli, R.H. Phenolic allelochemicals released by *Chenopodium murale* affect the growth, nodulation and macromolecule content in chickpea and pea. *Plant Growth Regul.*, **2007**, *51*, 119-128.

[52] Morone-Fortunato, I.; Montemurro, C.; Ruta, C.; Perrini, R.; Sabetta, W.; Blanco, A.; Lorusso, E.; Avato, P. Essential oils, genetic relationships and *in vitro* establishment of *Helichrysum italicum* (Roth) G. Don ssp. *italicum* from wild Mediterranean germplasm. *Ind. Crop. Prod*., **2010**, *32*, 639-649.

Received: November 14, 2011 Revised: December 19, 2011 Accepted: December 24, 2011