Journal of Global Biosciences
ISSN 2320-1355
Volume 5, Number 7, 2016, pp. 4386-4395
Website: www.mutagens.co.in
E-mail: submit@mutagens.co.in
researchsubmission@hotmail.com

Research Paper

ALLEOPATHIC EFFECT OF AROMATIC PLANTS: ROLE OF VOLATILE ESSENTIAL OILS

Bali, Aditi Shreeya[1], Daizy R. Batish[1] and Harminder Pal Singh[2]

[1]Department of Botany,
[2]Department of Environment Studies,
Panjab University, Chandigarh 160014, India.

Abstract
Allelopathic interactions, mediated through chemicals released by one plant, affects the growth and development of other plants growing in the vicinity. A great diversity of plants including trees exhibit allelopathy and the chemicals involved in this process are known as allelochemicals. These allelochemicals are released from the plants through leachation, decomposition of fallen plant parts, root exudation or as volatile components from aromatic plants. Among different allelochemicals, essential oils are one of the major constituent of number of higher plants, and are obtained by the process of steam distillation. The volatile and aromatic nature of essential oils helps in attracting pollinators, plant-plant signaling and tritrophic interactions. Essential oils are being investigated for their phytotoxic effect so that they can be used as potential herbicides.
Key words: Allelopathy, Allelochemicals, Volatile essential oils, Weed management.

INTRODUCTION

Plants are reservoirs of volatile compounds / natural plant products that are involved in various ecological functions e.g. as antiherbivore, antifungal / antibacterial compounds, phytotoxins, as attractants of pollinators and seed dispersers and plant-plant interactions including allelopathy [1]. The term allelopathy was coined by Molisch [2] and is derived from two Greek words alleon, 'of each other', and pathos, 'to suffer', which means mutual suffering. Later, [3] redefined the term as 'any direct or indirect, stimulatory or inhibitory effect of one plant (including microorganisms) on another through production of chemical compounds that escape into the environment'. The International Allelopathy Society (IAS) defined allelopathy as “any process which involves production of secondary metabolites by plants, algae, bacteria and fungi that influences the growth and development of biological systems” [4]. Theophrastus [5] was the first to observe inhibitory effect of chickpea, barley and bitter vetch etc. on other plants. Later, several reports documented the growth inhibitory effect of one plant on

other mediated by the release of chemicals into the environment [6][7][8]. However, due to lack of technological advancement, the progress in this field was slow.
Allelopathic interactions, mediated through chemicals released by one plant, affects the growth and development of other plants growing in the vicinity. However, at lower concentrations these chemicals may prove to be beneficial and may bring about positive effect on the recipient species [3]. A great diversity of plants including trees exhibit allelopathy and the chemicals involved in this process are known as allelochemicals. These allelochemicals are released from the plants through leachation, decomposition of fallen plant parts, root exudation or as volatile components from aromatic plants [3]. The inhibitory effects of plants on crops / weeds / other plants growing in its vicinity can be attributed to the release of allelochemicals from different parts of the tree *viz.* leaves, litter, stem, roots or even fruits resulting in poor growth of the plant [9].

ESSENTIAL OILS AND THEIR ROLE IN ALLELOPATHY

Among different allelochemicals, essential oils are one of the major constituent of number of higher plants, and are obtained by the process of steam distillation. These volatile oils are a complex mixture of ~ 20-70 components that are present in different amount. They remain stored within the plants in the special histological structures like secretory cavities, resin ducts, laticifers or glandular trichomes [10][11]. Environmental conditions like temperature, light and injury influence the quantity of essential oils emitted from the tissues [12]. Terpenes are the largest group of plant secondary metabolites and are the major constituents of essential oils. Essential oils are being investigated for their phytotoxic effect so that they can be used as potential herbicides. Some of the essential oil yielding aromatic plants are listed in Table 1 along with their chemical composition.

Table 1: List of essential oil yielding aromatic plants with their chemical composition

Name of the plant	Chemical composition	References
Citrus aurantium L.	Menthol, Menthone, Methyl esters, Pulegone, Piperitone	[13]
Cinnamomum zeylanicum Blume	Eugenol, Linalool, Piperitone	[14]
Juniperus communis L.	α-Pinene, Limonene, β-Pinene, Sabinene, Myrcene ,δ-3-Carene	[15]
Lavandula officinalis Chaix ex Vill.	β-Phellandrene, α-Terpineol, Limonene, Linalool	[16]
Syzygium aromaticum (L.) Merrill & Perry	Eugenol, Caryophyllene, Eugenyl acetate	[17]
Tagetes minuta L.	β-Phellandrene, Limonene, α-Ocimene, Dihydrotagetone, Tagetone, Tagetenone	[18]
Pimpinella anisum L.	Trans-anethole, methyl chavicol, γ-Himachalene, 2-Methylbutyrate,	[19]

	p-Anisaldehyde	
Artemisia scoparia Waldst. & Kit.	Citronellal, Acenaphthene, Caryophyllene oxide, *β*-Citronellol	[20]
Mentha piperita L.	*α*-Pinene, Sabinene, Myrcene, Limonene	[21]
Angelica archangelica L.	*α*-Pinene, *β*-Pinene, *p*-Cymene, Limonene, *δ*-3-Carene, *α*-Phellandrene, *β*-Phellandrene	[22]
Pinus armandii Franch.	Pinene, *p*-Cymene, Limonene, 3-Carene, Caryophyllene	[23]
Citrus sinensis (L.) Osbeck	*α*-Pinene, Camphene, *β*-Pinene, Sabinene, Myrcene, *α*-Phellandrene	[24]
Cymbopogon citrates (DC.) Stapf	Limonene, Geranial, Neral, Geraniol, Nerol, *β*-Caryophyllene	[25]
Rosmarinus officinalis L.	*α*-Pinene, D-Limonene, *β*-Pinene	[26]
Psidium cattleianum var. *lucidum* Hort.	Caryophyllene oxide, Bicyclo(4.4.0)dec-i-ene, 2, 3-Butanediol diacetate, Patchoulene	[27]
Juglans regia L.	*α*-pinene, *β*-pinene, *β*-caryophyllene, germacrene D, limonene	[28]
Cymbopogon nardus (L.) Rendle	Geraniol, trans-citral, cis-citral, geranyl acetate, citronellol, citronellal	[29]
Artemisia absinthium L.	*α*-pinene, sabinene, *β*-pinene, *α*-phellandrene, *p*-cymene and chamazulene	[30]
Rosa damascena Mill.	linalool, nerol, geraniol, 1-nonadecene, n-tricosane, hexatriacontane and n-pentacosane	[31]
Bauhinia pulchella Benth.	α-pinene, caryophyllene oxide and β-pinene	[32]
Bauhinia ungulate L.	caryophyllene oxide, E-caryophyllene and α-copaene	
Chromolaena laevigata (Lam.) R.M.King & H.Rob.	laevigatin, germacrene D, viridiflorol, bicyclogermacrene, limonene and α-pinene	[33]

ALLELOPATHIC EFFECT OF VOLATILE ESSENTIAL OILS

The essential oils are reported to be allelopathic / phytotoxic and possess potential to be used in weed management programmes [34][35][20]. Upon release from the plants these volatiles bring significant alterations in the structure and composition of the plant communities that leads to vegetation patterning [36].

Muller and Muller [34] reported the formation of bare zones (devoid of grasses) around the aromatic bushes of *Salvia* species owing to the release of certain volatile terpenes (mainly cineole, camphor, *α*-and *β*-pinenes) from these bushes. Later, Vaughn and Spencer [37] investigated the phytotoxicity of benzyl ether derivatives of some monoterpenes (carvone, citronellol, fenchone, geraniol, and pulegone) that were structurally similar to cinmethylin, a benzyl ether derivative of 1, 4- cineole on germination and growth of corn (*Zea mays* L.), soyabean (*Glycine max* [L.] Merr.), wheat (*Triticum aestivum* L.) and velvetleaf (*Abutilon theophrastii* Medik.). The authors observed that the benzyl ether derivatives of monoterpenes were more retardatory towards the weed species compared to cinmethylin.

Further, many reports suggested the weed management potential of *Eucalyptus* oil under laboratory and greenhouse conditions [38][39][40][41]. Kohli *et al*. [38] reported reduction in germination, chlorophyll content and cellular respiration in *Parthenium hysterophorus* L. in response to essential oil obtained from two *Eucalyptus* species, *E. globulus* Labill. and *E. citriodora* Hook. The oils caused loss of water content in the target species that led to wilting of the plant after 15 days of exposure to oils [38]. Batish *et al*. [39] studied the phytotoxicity of *E. citriodora* oil on some plant species namely, *Triticum aestivum L., Z. mays L., Raphanus sativus L., Cassia occidentalis L., Amaranthus viridis L.* and *Echinochloa crus-galli* (L.) Beauv. and among all the weed species studied, maximum inhibition in germination was observed in *A. viridis* and minimum in *R. sativus*. Moreover, the spray treatment of oil severely affected the photosynthetic machinery and cellular metabolism of 4-week-old plants of *C. occidentalis* and *E. crus-galli* [39]*. Later, the phytotoxic potential of E. citriodora* was also evaluated against the germination and growth of *P. minor* under laboratory and pot conditions [40]. The results revealed that essential oil of *E. citriodora* caused visible symptoms like chlorosis and necrosis and caused electrolyte leakage in the plants which might be attributed to the volatile monoterpenes present in the oil [40].

Later, Scrivanti *et al*. [42] observed phytotoxicity of *T. minuta* and *Schinus areira* L. essential oil towards the growth of *Z. mays*. They identified monoterpenes viz. *α*- and *β*-pinene, tagetone, limonene and ocimene which might be responsible for the phytotoxicity. Further, the reduced growth of the plant may be due to the oxidative damage caused by the oil as indicated by increased amount of malondialdehyde in the plant [42].

The phytotoxicity of essential oil from *Eucalyptus globulus* Labill., *Melaleuca alternifolia* Miaden and Betche ex Cheel, *Melisa officinalis* L., *Rosmarinus officinalis* L., *Syzygium aromaticum* (L.) Merrill and Perry and *Citrus limonum* Risso. was investigated on peroxidase activity of some leafy vegetables *viz. Beta vulgaris* L., *Spinacea oleracea* L., *L. sativa*, *L. sativa* var. *capitata* and *Brassica oleracea* var. *capitata* L.. The results revealed clove oil to be most effective [43].

Kordali *et al*. [44] determined the phytotoxic activity of essential oil from aerial parts of *Origanum acutidens* (Hand.-Mazz) Letswaart and its monoterpenes constituents like carvacrol, *p*-cymene and thymol on germination and seedling growth of *Amaranthus retroflexus L., Chenopodium album* L. and *Rumex crispus L. The results showed that oil and its constituents, carvacrol and thymol completely inhibited the germination and growth of all the tested plants and the observed phytotoxicity of oil may be attributed to the presence of major component, carvacrol in the plant [44]. Further, the phytotoxicity of Achillea gypsicola* Hub-Mor. and *A. bierberstinii* Afan. were investigated against five weeds, namely, *Amaranthus retroflexus* L., *Chenopodium album* L., *Cirsium arvense* L. (Scop.), *Lactuca serriola* L. and *Rumex crispus* L. [45]. The results revealed strong inhibitory effect of oil on germination and growth of *A. retroflexus*, *C. arvense* and *L. serriola* and, therefore, suggested their potential to be used as herbicide in future [45].

Kaur *et al*. [46] assessed the phytotoxic effect of *Artemisia scoparia* Waldst. & Kit. essential oil towards weedy species like *Achyranthes aspera L.*, *Cassia occidentalis L.*, *Parthenium hysterophorus L.*, *E. crus-galli (L.) Beauv.*, and *Ageratum conyzoides L.* The oil significantly inhibited the emergence and growth of all the weeds and the phytotoxicity might be attributed to the interference of oil with the growth and physiological processes of weed species [46].

Satyal *et al*. [47] studied the phytotoxicity of essential oil obtained from rhizome and leaves of *Acorus calamus* L. The results revealed stronger allelopathic potential of rhizome essential oil towards the germination and seedling growth of *Lolium perenne* L. compared to *Lactuca sativa* L. [47]. The germination and seedling growth of *E. crus-galli* was reduced upon exposure to *Cymbopogon citratus* (DC.) Stapf. essential oil [48]. Further, the oil also inhibited the α-amylase activity of the seeds and interfered with the photosynthetic machinery of the plant [48].

Bouajaj *et al*. [49] evaluated the phytotoxic activity of *Ruta chalepensis* L. essential oil and identified undecan-2-one, nonan-2-one, limonene and decanone as the major components in the leaves of the plant. The phtotoxic potential of oil was determined by studying the effect of oil on germination and seedling growth of two weed species, *Triticum durum* L. and *Phalaris canariensis* L. [49].

Marichali *et al*. [50] observed reduction in germination and radicle growth of *P. minor* and *T. aestivum* in response to *Carum carvi* L. essential oil, however, the effect was more on *P. minor* compared to *T. aestivum*.

Singh *et al*. [51] investigated the phytotoxic effect of essential oil from roots of *Senecio amplexicaulis* Kunth. on *P. minor* and *T. aestivum* L. The essential oil contained α-phellandrene, *o*-cymene and β-ocimene as the major constituents. The results revealed reduction in percentage of seed germination in response to higher concentration of oil [51].

Apostolico *et al*. [52] evaluated the phytotoxic potential of *Peganum harmala* L. essential oil from five different regions on germination and initial radicle growth of *Raphanus sativus* L., *Lepidium sativum* L., *Ruta graveolens* L. The essential oil contained eugenol as the major component and the results indicated inhibitory effect of oils on germination and radicle elongation of test plants.

ROLE OF ALLELOPATHY / ALLELOCHEMICALS IN WEED MANAGEMENT

Weeds, being natural barrier to human activities and health, cause undesirable changes in plant communities. They interfere with the growth and development of crops affecting its quality and yield. Various mechanical, biological and chemical methods are applied for controlling weeds. Of these, mechanical and biological methods fail to provide adequate weed control and thus chemical methods are used worldwide. Because of this, agricultural practices rely mainly on the use of huge amount of herbicides to manage these weeds. Indiscriminate use of synthetic herbicides for controlling weeds has not only deteriorated the environment quality but has also led to development of herbicidal resistance among weeds [53] as they are not biodegradable and leave residual activity in the soil. Therefore, large emphasis is given on the use of allelochemicals in managing weeds to sustain continued crop yield [54].

Natural plant products are receiving much attention of the scientists for their role in allelopathy that can further be exploited for weed management owing to their environmentally benign properties including biodegradable nature and minimum mammalian toxicity [55]. Among different natural compounds, allelochemicals (chemicals responsible for allelopathy) are being explored as an important tool in weed management because of their structural and chemical diversity [56]. Various physiological and biochemical processes like cell division, pollen germination, mineral uptake, stomatal movement, photosynthesis, respiration, amino acid synthesis, nitrogen fixation, specific enzyme activities etc. are affected by the application of allelochemicals [57]. Several reviews have highlighted the potential importance of allelochemicals as herbicides [55][58] as they are environmentally benign, biodegradable, possess low mammalian toxicity and novel target sites *i.e.* different from those of synthetic herbicides [55].

CONCLUSION

Aromatic plants are reservoirs of volatile essential oils that are known to be allelopathic and possess novel target sites different from the commercially used synthetic herbicides and thus can be used for the management of weeds under sustainable agriculture programmes.

ACKNOWLEDGEMENT

Aditi Shreeya Bali is thankful to Department of Science and Technology for providing research assistance in the form of INSPIRE fellowship.

REFERENCES

[1] Langenheim, J. H. 1994. Higher plant terpenoids: a phytocentric overview of their ecological roles. Journal of chemical ecology **20:** 1223–1280.

[2] Molisch, H., 1937. Der Einfluss einer Pflanze auf die andere-Allelopathie. Jena, Germany: Gustav Fischer.

[3] Rice, E. L. 1984. Allelopathy. Academic Press, Orlando, FL.

[4] Macías, F. A., Molinillo, J. M., Varela, R. M. and Galindo, J. C. 2007. Allelopathy—a natural alternative for weed control. Pest Management Science **63**: 327–348.

[5] Theophrastus, Enquiry into Plants, translated by Hort AF. Loeb Classical, Harvard University Press, Cambridge, MA (1980).

[6] Culpeper, N. 1633. English Physitian and Complete Herball. London: Foulsham. (Reprinted, 1955).

[7] Young, A. 1804. The Farmers Calender. London.

[8] De Candolle, M. A. P. 1832. Physiologiae Vegetale Tomme III. Bechet Jeune, Lib., Fac. Med., Paris, France, pp. 1474–1475.

[9] Rizvi, S. J. H., Tahir, M., Rizvi, V., Kohli, R. K. and Ansari, A. 1999. Allelopathic interaction Agroforestry systems. Critical Reviews in Plant Sciences **18**: 773–796.

[10] Harrewijn, P., van Oosten, A. M., Piron, P. M. 2001. *Natural terpenoids as messengers: A multidisciplinary study of their production, biological functions and practical applications.* Kluwer, Dordrecht, Netherlands.

[11] Wang, G., Tian, L., Aziz, N., Broun, P., Dai, X., He, J., King, A., Zhao, P. X. and Dixon, R. A. 2008. Terpene biosynthesis in glandular trichomes of hop. Plant Physiology **148**: 1254–1266.

[12] Filella, I., Wilkinson, M. J., Llusià, J., Hewitt, C. N. and Peñuelas, J. 2007. Volatile organic compounds emissions in Norway spruce (*Picea abies*) in response to temperature changes. Physiologia Plantarum **130**: 58–66.

[13] Lota, M. L., de Rocca Serra, D., Jacquemond, C., Tomi, F. and Casanova, J. 2001. Chemical variability of peel and leaf essential oils of sour orange. Flavour and Fragrance Journal 16: 89–96.
[14] Raina, V. K., Srivastava, S. K., Aggarwal, K. K., Ramesh, S. and Kumar, S. 2001. Essential oil composition of *Cinnamomum zeylanicum* Blume leaves from Little Andaman, India. Flavour and Fragrance Journal **16**: 374–376.
[15] Angioni, A., Barra, A., Russo, M. T., Coroneo, V., Dessi, S. and Cabras, P. 2003. Chemical composition of the essential oils of *Juniperus* from ripe and unripe berries and leaves and their antimicrobial activity. Journal of Agriculture and Food Chemistry **51**: 3073–3078.
[16] Afsharypour, S. and Azarbayejany, N. 2006. Chemical Constituents of the Flower Essential Oil of *Lavandula officinalis* Chaix. from Isfahan (Iran). Iranian Journal of Pharmaceutical Sciences **2**: 169–172.
[17] Alma, H. M., Ertas, M., Nitz, S. and Kollmannsberger, H. 2007. Reasearch on essential oil content and chemical composition of Turkish clove (*Syzygium aromaticum* L.). BioResources **2**: 265–269.
[18] Chamorro, E. R., Ballerini, G., Sequeira, A. F., Velasco, G. A. and Zalazar, M. S. 2008. Chemical composition of essential oil from *Tagetes minuta* L. leaves and flowers. Journal of Argentine Chemical Society **96**: 80–86.
[19] Orav, A., Raal, A. and Arak, E. 2008. Essential oil composition of *Pimpinella anisum* L. fruits from various European countries. Natural product research **22**: 227–232.
[20] Singh, H.P., Kaur, S., Mittal, S., Batish, D.R., Kohli, R.K., 2009. Essential oil of *Artemisia scoparia* inhibits plant growth by generating reactive oxygen species and causing oxidative damage. Journal of Chemical Ecology **35**: 154–162.
[21] Kizil, S., Hasimi, N., Tolan, V., Kilinc, E. and Yuksel, U. 2010. Mineral content, essential oil components and biological activity of two mentha species (*M. piperita* L., *M. spicata* L.). Turkish Journal of Field Crops **15**: 148–153.
[22] Pathak, S., Wanjari, M. M., Jain, S. K. and Tripathi, M. 2010. Evaluation of antiseizure activity of essential oil from roots of *Angelica archangelica* Linn. in mice. Indian journal of pharmaceutical sciences **72**: 371–375.
[23] Yang, X., Zhao, H. T., Wang, J., Meng, Q., Zhang, H., Yao, L., Zhang, Y. C., Dong, A. J., Ma, Y., Wang, Z. Y., Xu, D. C. and Ding, Y. (2010). Chemical composition and antioxidant activity of essential oil of pine cones of *Pinus armandii* from the Southwest region of China. Journal of Medicinal Plants Research **4**: 1668–1672.
[24] Azar, P. A., Nekoei, M., Larijani, K. and Bahraminasab, S. 2011. Chemical composition of the essential oils of *Citrus sinensis* cv. valencia and a quantitative structure–retention relationship study for the prediction of retention indices by multiple linear regression. Journal of Serbian Chemical Society **76**: 1627–1637.
[25] Bassolé, I. H. N., Lamien-Meda, A., Bayala, B., Obame, L. C., Ilboudo, A. J., Franz, C., Novak, J., Nebié, R. C. and Dicko, M. H. 2011. Chemical composition and antimicrobial activity of *Cymbopogon citratus* and *Cymbopogon giganteus* essential oils alone and in combination. Phytomedicine **18**: 1070–1074.
[26] Kadri, A., Zarai, Z., Chobba, I. B., Békir, A., Gharsallah, N., Damak, M. and Gdoura, R. 2011. Chemical constituents and antioxidant properties of *Rosmarinus officinalis* L. essential oil cultivated from the South-Western of Tunisia. Journal of Medicinal Plants Research **5**: 6502–6508.

[27] Chalannavar, R. K., Narayanaswamy, V. K., Baijnath, H. and Odhav, B. 2012. Chemical composition of essential oil of *Psidium cattleianum* var. *lucidum* (Myrtaceae). African Journal of Biotechnology **11**: 8341–8347.
[28] Rather, M. A., Dar, B. A., Dar, M. Y., Wani, B. A., Shah, W. A., Bhat, B. A., Ganai, B. A., Bhat, K. A., Anand, R. and Qurishi, M. A. 2012. Chemical composition, antioxidant and antibacterial activities of the leaf essential oil of *Juglans regia* L. and its constituents. Phytomedicine **19**: 1185–1190.
[29] Nakahara, K., Alzoreky, N. S., Yoshihashi, T., Nguyen, H. T. and Trakoontivakorn, G. 2013. Chemical composition and antifungal activity of essential oil from *Cymbopogon nardus* (citronella grass). Japan Agricultural Research Quarterly **37**: 249–252.
[30] Mohammadi, A., Sani, T. A., Ameri, A. A., Imani, M., Golmakani, E. and Kamali, H. 2014. Seasonal variation in the chemical composition, antioxidant activity, and total phenolic content of *Artemisia absinthium* essential oils. Pharmacognosy research **7**: 329–334.
[31] Yassa, N., Masoomi, F., Rankouhi, S. R. and Hadjiakhoondi, A. 2015. Chemical composition and antioxidant activity of the extract and essential oil of *Rosa damascena* from Iran, population of Guilan. DARU Journal of Pharmaceutical Sciences **17**: 175–180.
[32] De Sousa, L. M., de Carvalho, J. L., Gois, R. W., da Silva, H. C., Santiago, G. M., Lemos, T. L., Ariaga, A. M. C., Alves, P. B., de Matos, I. L., Militão G. C. G., da Silva, P. B. N. and da Silva, T. G. 2016. Chemical composition, larvicidal and cytotoxic activities of the essential oils from two Bauhinia species. Records of Natural Products **10**: 341–348.
[33] Valarezo, E., Arias, A., Cartuche, L., Meneses, M., Ojeda-Riascos, S. and Morocho, V. 2016. Biological Activity and Chemical Composition of the Essential Oil from *Chromolaena laevigata* (Lam.) RM King & H. Rob.(Asteraceae) from Loja, Ecuador. Journal of Essential Oil Bearing Plants **19**: 384–390.
[34] Muller, W. H. and Muller, C. H. 1964. Volatile growth inhibitors produced by *Salvia* species. Bulletin of the Torrey Botanical Club **91**: 327–330.
[35] Batish, D. R., Singh, H. P., Kohli, R. K. and Kaur, S. (2008). Eucalyptus essential oil as a natural pesticide. Forest Ecology and Management **256**: 2166–2174.
[36] Muller, C. H. 1965. Inhibitory terpenes volatilized from Salvia shrubs. Bulletin of the Torrey Botanical Club **92**: 38–45.
[37] Vaughn, S. F. and Spencer, G. F. 1996. Synthesis and herbicidal activity of modified monoterpenes structurally similar to cinmethylin. Weed science **44**: 7–11.
[38] Kohli, R. K., Batish, D. R. and Singh, H. P. 1998. Eucalypt oils for the control of parthenium (*Parthenium hysterophorus* L.). Crop Protection **17**: 119–122.
[39] Batish, D. R., Setia, N., Singh, H. P. and Kohli, R. K. 2004. Phytotoxicity of lemon-scented eucalypt oil and its potential use as a bioherbicide. Crop Protection **23**: 1209–1214.
[40] Batish, D. R., Singh, H. P., Setia, N., Kohli, R. K., Kaur, S. and Yadav, S. S. (2007). Alternative control of littleseed canary grass using eucalypt oil. Agronomy for Sustainable Development **27**: 171–177.
[41] Setia, N., Batish, D. R., Singh, H. P. and Kohli, R. K. (2007). Phytotoxicity of volatile oil from *Eucalyptus citriodora* against some weedy species. Journal of Environmental Biology **28**: 63–66.

[42] Scrivanti, L. R., Zunino, M. P. and Zygadlo, J. A. (2003). *Tagetes minuta* and *Schinus areira* essential oils as allelopathic agents. Biochemical Systematics and Ecology **31**: 563–572.

[43] Ponce, A. G., Del Valle, C. E. and Roura, S. I. (2004). Natural essential oils as reducing agents of peroxidase activity in leafy vegetables. LWT-Food Science and Technology **37**: 199–204.

[44] Kordali, S., Cakir, A., Ozer, H., Cakmakci, R., Kesdek, M. and Mete, E. (2008). Antifungal, phytotoxic and insecticidal properties of essential oil isolated from Turkish *Origanum acutidens* and its three components, carvacrol, thymol and p-cymene. Bioresource Technology **99**: 8788–8795.

[45] Kordali, S., Cakir, A., Akcin, T. A., Mete, E., Akcin, A., Aydin, T. and Kilic, H. (2009). Antifungal and herbicidal properties of essential oils and n-hexane extracts of *Achillea gypsicola* Hub-Mor. and *Achillea biebersteinii* Afan.(Asteraceae). Industrial Crops and Products **29**: 562–570.

[46] Kaur, S., Singh, H. P., Mittal, S., Batish, D. R. and Kohli, R. K. (2010). Phytotoxic effects of volatile oil from *Artemisia scoparia* against weeds and its possible use as a bioherbicide. Industrial Crops and Products **32**: 54–61.

[47] Satyal, P., Paudel, P., Poudel, A., Dosoky, N. S., Moriarity, D. M., Vogler, B. and Setzer, W. N. (2013). Chemical compositions, phytotoxicity, and biological activities of *Acorus calamus* essential oils from Nepal. Natural Product Communication **8**: 1179–1181.

[48] Poonpaiboonpipat, T., Pangnakorn, U., Suvunnamek, U., Teerarak, M., Charoenying, P. and Laosinwattana, C. (2013). Phytotoxic effects of essential oil from *Cymbopogon citratus* and its physiological mechanisms on barnyardgrass (*Echinochloa crus-galli*). Industrial Crops and Products **41**: 403–407.

[49] Bouajaj, S., Romane, A., Benyamna, A., Amri, I., Hanana, M., Hamrouni, L. and Romdhane, M. (2014). Essential oil composition, phytotoxic and antifungal activities of *Ruta chalepensis* L. leaves from High Atlas Mountains (Morocco). Natural Product Research **28**: 1910–1914.

[50] Marichali, A., Hosni, K., Dallali, S., Ouerghemmi, S., Ltaief, H. B. H., Benzarti, S., Kerkeni, A. and Sebei, H. (2014). Allelopathic effects of *Carum carvi* L. essential oil on germination and seedling growth of wheat, maize, flax and canary grass. Allelopathy Journal **34**: 81–94.

[51] Singh, R., Ahluwalia, V., Singh, P., Kumar, N., Prakash Sati, O. and Sati, N. (2016). Antifungal and phytotoxic activity of essential oil from root of *Senecio amplexicaulis* Kunth.(Asteraceae) growing wild in high altitude-Himalayan region. Natural Product Research **30**: 1–5.

[52] Apostolico, I., Aliberti, L., Caputo, L., De Feo, V., Fratianni, F., Nazzaro, F., Souza, S. F. and Khadhr, M. (2016). Chemical composition, antibacterial and phytotoxic activities of *Peganum harmala* seed essential oils from five different localities in Northern Africa. Molecules **21**: 1–13.

[53] Heap, I. (2016). The international survey of herbicide resistant weeds. www.weedscience.com (accessed 14.05.2016).

[54] Dayan F. E. and Duke S. O. 2014. Natural compounds as next generation herbicides. Plant Physiology 166: 1090–1105.

[55] Dayan, F. E., Owens, D. K. and Duke, S. O. (2012). Rationale for a natural products approach to herbicide discovery. Pest Management Science **68**: 519–528.

[56] Duke, S. O. and Dayan, F. E. (2015). Discovery of new herbicides modes of action with natural phytotoxins. American Chemical Society Symposium Series **1204:** 79–92.
[57] Chon, S. U. and Nelson, C. J. (2010). Allelopathy in Compositae plants. A review. Agronomy for Sustainable Development **30**: 349–358.
[58] Soltys, D., Krasuska, U., Bogatek, R. and Gniazdowska, A. (2013). Allelochemicals as bioherbicides—present and perspectives. In: *Herbicides—current research and case studies in use* eds. Price, A. J. and Kelton, J. A. *In tech Publisher* 517–542.