Chapter 5

Potentially Phytotoxic of Chemical Compounds Present in Essential Oil for Invasive Plants Control: A Mini-Review

Mozaniel Santana de Oliveira,
Wanessa Almeida da Costa,
Priscila Nascimento Bezerra,
Antonio Pedro da Silva Souza Filho and
Raul Nunes de Carvalho Junior

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.74346

Abstract

The control of invasive plants is still carried out with the use of synthetic chemical agents that may present high toxicity and, consequently, be harmful to humans and animals. In Brazil, especially in the Amazon, small producers use this kind of technique in a rustic way, with brushcutters or fire. In this sense, the search for natural agents with bioherbicide potential becomes necessary. Examples of these agents are the essential oils that over the years have been shown to be a viable alternative to weed control. Thus, this review aims to show the potentially phytotoxic activity of allelochemicals present in essential oils of different aromatic plants.

Keywords: natural products, essential oils, allelochemicals, allelopathy

1. Introduction

The performance of agricultural activity in tropical regions, both in fertile and in low fertility soils, has been limited by the occurrence of a series of extremely aggressive and diverse plants, called weeds. The main consequence of crop infestation by these plants is increasing costs to maintain the crops and reduction of productivity and its consequent competitive capacity. These plants may also represent an additional problem for farmers either because they are often toxic to different animals or because they are permanent sources for the spread of diseases to crop plants [1]. In this context, weed management and control become crucial both from the point of view of crop productivity and the profitability of the farming system.

In modern agriculture, where high yields are expected, in the face of increasing demands for food – due to the increasing world population – the control of these plants has been made, basically, by the use of chemical herbicides. However, such a procedure may not be sustainable over time, especially because it conflicts with the interests of modern society, which is increasingly concerned with the quality of food and with the preservation of natural resources. At the same time, the reduction in the efficiency of the current products available in the market has been observed as a consequence of the appearance of resistant plants [2, 3], leading to an increase in the use of herbicides or the contractions employed, which only increases the problem. All these factors point to the need of science to make available new and revolutionary methods of weed control.

A viable alternative to this challenge are the numerous chemically diverse compounds produced by plants that may offer new chemical structures capable of efficiently replace those already available in the market. In this line, crude extracts and isolated or associated chemical substances can be an excellent strategy to partially or totally replace the use of herbicides.

Over the last decades, different chemical compounds with bioherbicidal properties have been isolated and identified in different plants [4–7]. Among the many chemical classes with potential use in weed management, the secondary metabolites present in essential oils can be highlighted, since the different chemical classes of volatile compounds are notable for the wide potential of use in different activities of interest for humanity and specifically in the management of weeds.

2. Allelopathy history

Allelopathy is the chemical interaction between plants and other living organisms [8]. There are two types of interactions between plants: a phytotoxic one, which inhibits the germination of seeds and the development of the radicle and hypocotyl [9], and a stimulatory effect, which favors the development of the plant [10]. The chemical substances responsible for the allelopathic effect are called allelochemicals [11].

The allelopathy is a relatively new science, having its basic concepts established over the last 8 decades. However, chemical interactions among plants are not exactly new, since reports on the subject are found in old references. [12–16]. In the 1800s, several phenomena were attributed to the chemical interaction among plants [17]. In the early 1900's, [18] reported the presence of toxic compounds produced by plants that could be extracted from the soil. The first reports proving the interference promoted by chemical compounds were developed in the 1960's [19], showing that the volatile compounds were affecting the dynamics among plants.

3. Control of invasive plants

Currently, the chemical control method is the most used to inhibit the growth of invasive plants, which includes the use of synthetic herbicides, in large quantities, mainly by large producers, as reported by some authors [20, 21]. The use of synthetic and toxic chemical herbicides in management areas promotes the death of weeds in a selective way and, consequently, it ends the competition among the plants, helping to increase the production of green mass in the pasture [22]. The increasing use of agrochemicals may represent an unsustainable practice because these pesticides can pollute the environment and promote the contamination of various animal species. Also, new insecticide-resistant insects are appearing and invasive plants that are tolerant to modern herbicides are becoming more frequent [23].

Weed resistance to herbicides may be related to an evolutionary process; however, some developments of resistant weed biotypes are imposed by agriculture through selection pressure caused by the intensive use of herbicides. Weed resistance to herbicides may result from biochemical, physiological, morphological or phenological changes of certain invasive plant biotypes. Many cases of resistance to herbicides result from either the alteration of the site of action of the herbicide or the increase of its metabolism, or the departmentalization and compartmentalization of the herbicide in the plant [24, 25]. This way, allelopathy can be a natural alternative for the control of invasive plants.

4. Volatile allelochemicals

Weeds promote two basic types of interference in agricultural crops: allelospoly and allelopathy. Allelospoly is the type of interference promoted by competition for essential factors to the species survival, such as water, nutrients and physical space. Allelopathy involves the production of allelochemicals and subsequent release into the environment [26]. Almost all allelochemicals exist in conjugated, non-toxic forms. The toxic fragment can be released after exposure to stress or after tissue death [27].

The use of allelopathy for weed control may be an ecologically viable alternative [28]. Thus, the use of essential oils with phytotoxic potential is becoming widespread, since the allelochemicals present in these oils generally have low cytotoxicity. For example, [29] evaluated the effect of *Carum carvis* essential oils rich in carvone (71.08%) and limonene (25.42%), and verified that this oil has a strong phytotoxic activity on seed germination and radicle elongation of *Linum usitatissimum*, *Phalaris canariensis* and *Triticum aestivum*.

Another example is the eucalypt essential oil that has a rich chemical composition in 1,8-cineole (58.3%), α-pinene (17.3%) and α-thujene (15.5%), which significantly inhibited seed germination of *Sinapis arvensis*, *Diplotaxis harra* and *Trifolium campestre*, in different intensities according to the recipient species, demonstrating that each species has a different specificity. In addition, the application of post-emergence oil causes inhibition of chlorophyll production, leading to injuries such as chlorosis, necrosis and even complete wilting of plants [30].

Plant species such as *Origanum onites L.* and *Rosmarinus officinalis L.* also show strong allelopathic activity on species of *Poaceae* and invasive plants, by suppressing germination rate and elongation of radicle and hypocotyl [31]. The phytotoxic effects related to these two species of aromatic plants may be related to their rich chemical composition in the oxygenated monoterpenes 1,8-cineole, linalool, camphor and carvacrol and the monoterpene hydrocarbon p-cymene [32–35], however, compounds found in lower concentrations as methyl phenylpropanoids have also demonstrated good allelopathic activity [36].

In the case of essential oils for the control of invasive plants, it is usually analyzed the effects of individual form, attributing the phytotoxic activity to only one component [37, 38]. However, the effects of volatile oils can also be related to the mixture of compounds, such as *Artemisia scoparia* oil which has a mixture of compounds such as monoterpene hydrocarbons, oxygenated monoterpenes, sesquiterpene hydrocarbons, oxygenated sesquiterpenes, aliphatic compounds and other aromatic compounds [39]. The chemical composition of the essential oils depends on the biosynthetic path of the different classes of compounds, as can be observed in **Figure 1**, which brings the biosynthesis of some classes of volatile compounds.

Compounds such as eucalyptol, β-phellandrene, hexyl butanoate, *p*-cymene, α-ionone, (z)-3-octen-1-ol, theaspirane a, vitispirane, dihydro-(−)-neoclovene, β-caryophyllene, (e)-2-octen-1-ol, a-terpineol, dehydro-ar-ionene, methyl salicylate, (z)-b-damascenone, (z)-dehydro-ar-ionene,

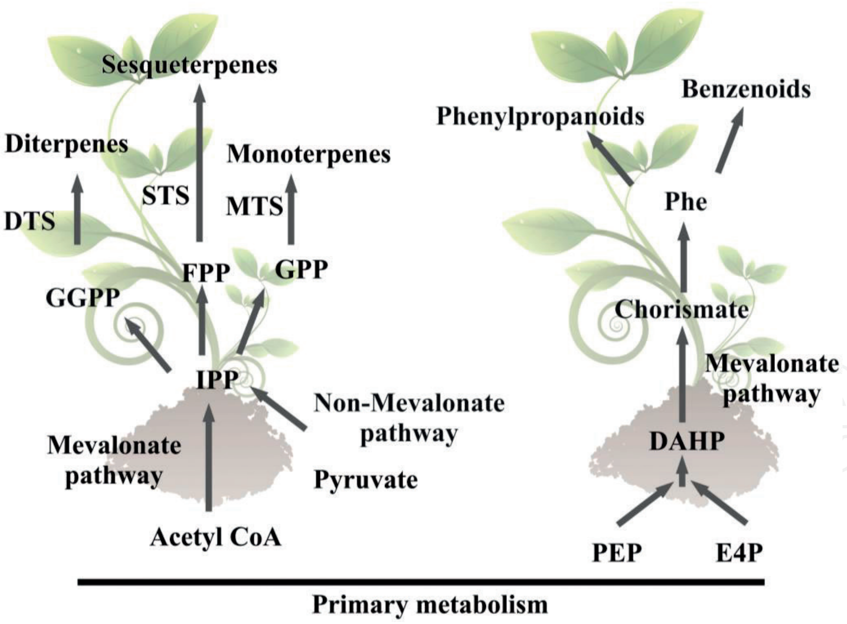

Figure 1. Biosynthesis of plant volatiles. Overview of biosynthetic pathways leading to the emission of plant volatile organic compounds. The plant precursors originate from primary metabolism. Abbreviations: DTS: Diterpene synthase; FPP: farnesyldiphosphate; GGPP: geranylgeranyldiphosphate; GLVs: green-leaf volatiles; GPP: geranyldiphosphate; IPP: isopentenyl pyrophosphate; MTS: Monoterpene synthase; STS: Sesquiterpene synthase; DAHP: 3-deoxy-D-arabinoheptulosonate-7 phosphate; E4P: erythrose 4-phosphate; PEP: phosphoenolpyruvate; Phe: phenylalanine. This flowchart was adapted from [40] and [41].

http://dx.doi.org/10.5772/intechopen.74346

10-(tetrahydro-pyran-2-yloxy)-tricyclo[4.2.1(2,5)]decan-9-ol, (−)-caryophyllene oxide, dihydro-β-ionone, viridiflorol, cubenol, caryophyllene, α-bisabolol oxide-b, tetracosane and *n*-hexadecane can be found in *Anisomeles indica* essential oil and also present good phytotoxic activity against invasive plants [42]. As well as *P. heyneanus Benth* essential oils, rich in patchouli alcohol, α-bulnesene, α-guaiene, seichelene and α-patchulene, and *P. hispidinervium* C. DC oils, rich in safrole, terpinolene, (E)-β-ocimene, δ-3-carene and pentadecane [43].

4.1. Monoterpenes

The monoterpenes have presented good phytotoxic activity, and reports of the use of these compounds to control plants refer to the 1960s [44]. This activity depends on the structural

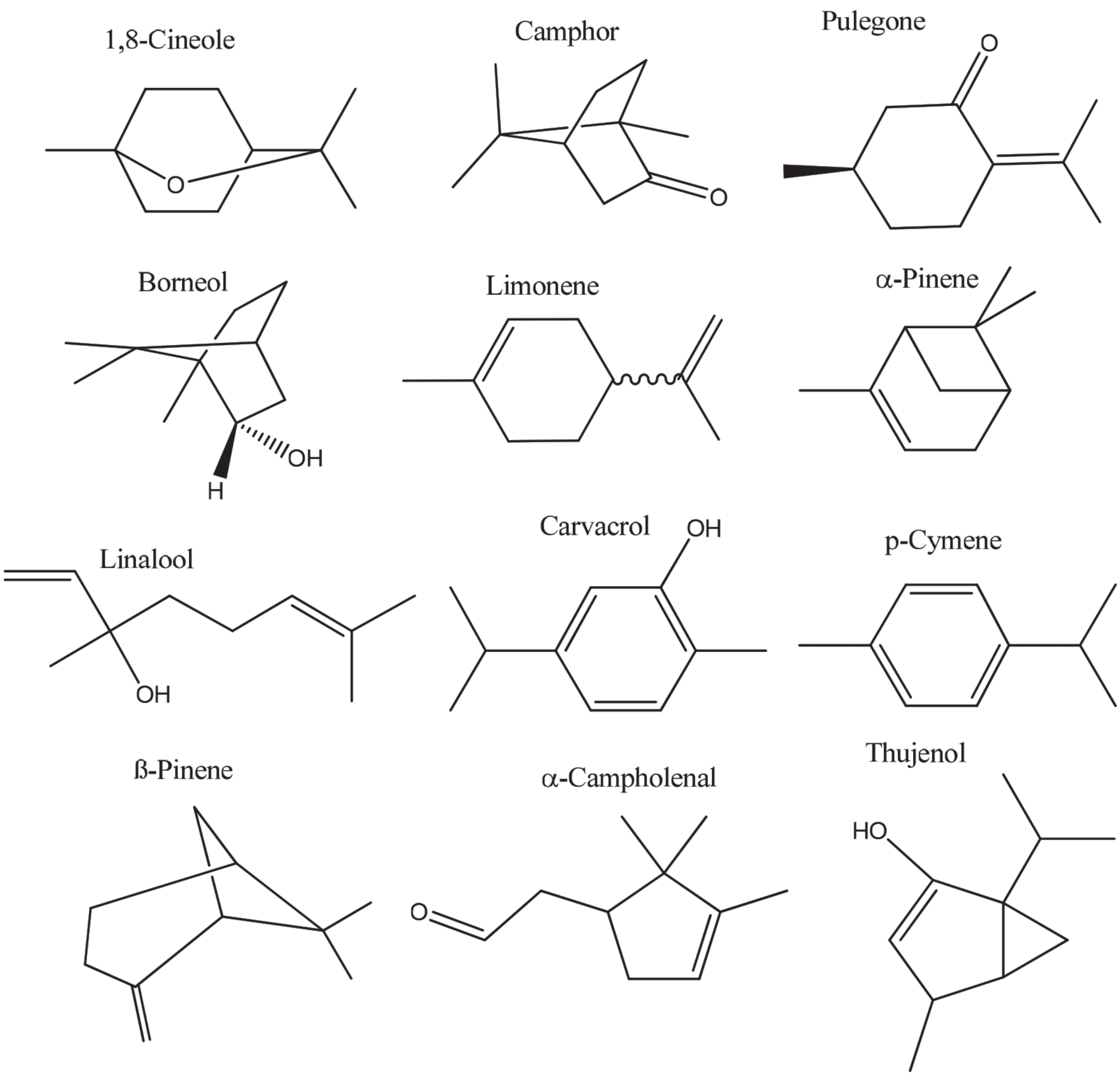

Figure 2. Chemical structures of oxygenated and non-oxygenated monoterpenes with bioherbicidal action.

characteristics of the molecules; for example, oxygenated monoterpenes exhibit different effects on germination and seedling development, and also alter cellular respiration, which impairs energetic metabolism [33, 34]. However, these phytotoxic effects promoted by a chemical species depend on its concentration, for example, *Lactuca sativa* essential oil composed essentially of α-pinene (16.00%), 1,8-cineole (66.93%) and pimonene (10.04%) presents different rates of germination inhibition [45].

In general, oxygenated monoterpenes have the highest phytotoxic effects over non-oxygenated [46]. However, there are non-oxygenated volatile molecules such as limonene which also have good phytotoxic activity [47]. Some monoterpenes had high inhibitory activity on germination and radicle elongation, and this may be related to the anatomical and physiological changes in the host plants, as well as to the reduction in some organelles such as mitochondria, and accumulation of lipid globules in the cytoplasm [48]. In **Figure 2**, the chemical structures of some monoterpenes with phytotoxic activity can be observed.

4.2. Sesquiterpenes

Bioassays have demonstrated that the sesquiterpenic allelochemicals β-cariofilene, β-copaene, spathulenol, germacrene B, bicyclogermacrene, globulol, viridiflorol, a-guaiene, and g-elemene have presented phytotoxity against various invasive plants and, in some cases, promote inhibition of other plants development, when they are close to species that produce these secondary metabolites [49–51]. Authors compared the effects of essential oils rich in sesquiterpenes and others rich in monoterpenes and found that the effects presented by sesquiterpenes, in some cases, may be smaller in relation to the affections exhibited by monoterpenes [52]. **Figure 3** shows the chemical structures of oxygenated and non-oxygenated sesquiterpenes with phytotoxic action.

However, this depends largely on the presence of oxygenated and non-oxygenated, cyclic or acyclic molecules, because depending on the molecular conformation the allelopathic effect may be higher or lower [53, 54]. This justifies the results obtained by other authors [55], who analyzed the effects of fractions of essential oils of *E. adenophorum,* of the inflorescence region, rich in sesquiterpenes, and its root rich in monterpenes. When the oils were tested at the same concentration (1 μL/mL), they inhibited germination and seedling elongation at the same ratio.

4.3. Phenylpropanoids

Phenylpropanoids are a class of secondary metabolites that are also naturally present in plants, and have exhibited strong phytotoxic activity against invasive plants. In 2016, [9] demonstrated that eugenol is the main active ingredient of clove essential oil and is also the agent possibly promoting phytotoxic activity against the invasive plants *Mimosa pudica* and *Senna obtusifolia*. Other authors also report the potentially allelopathic activity

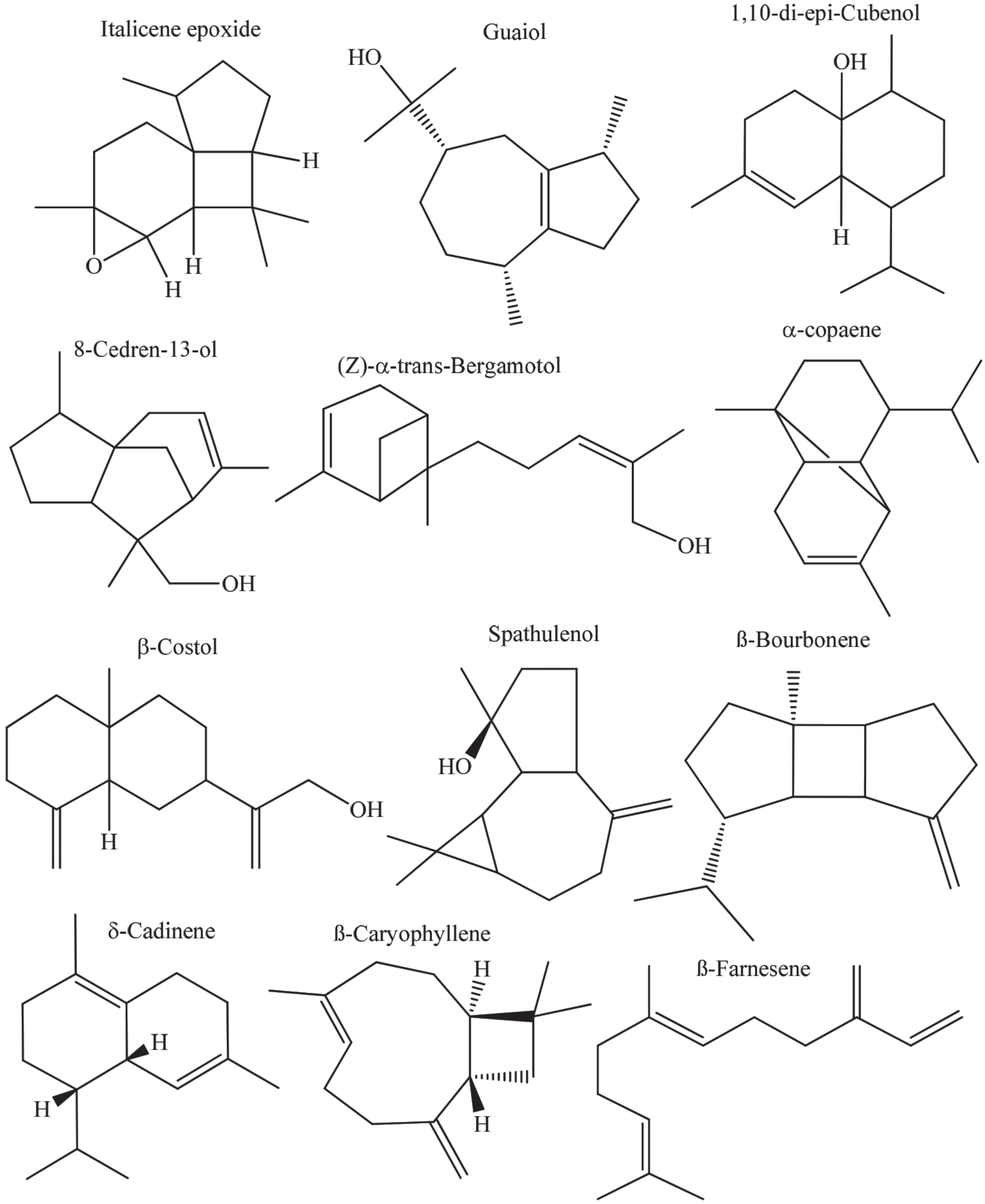

Figure 3. Chemical structures of oxygenated and non-oxygenated sesquiterpenes with bioherbicidal action.

of clove essential oil *Syzygium aromaticum* [56–58]. In addition to eugenol, other phenylpropanoids present in essential oils with phytotoxic activity are eugenyl acetate, safrole, methyl eugenol, anethole, myristicin, estragole, anethole and trans-anethole [36, 59–64]. **Figure 4**

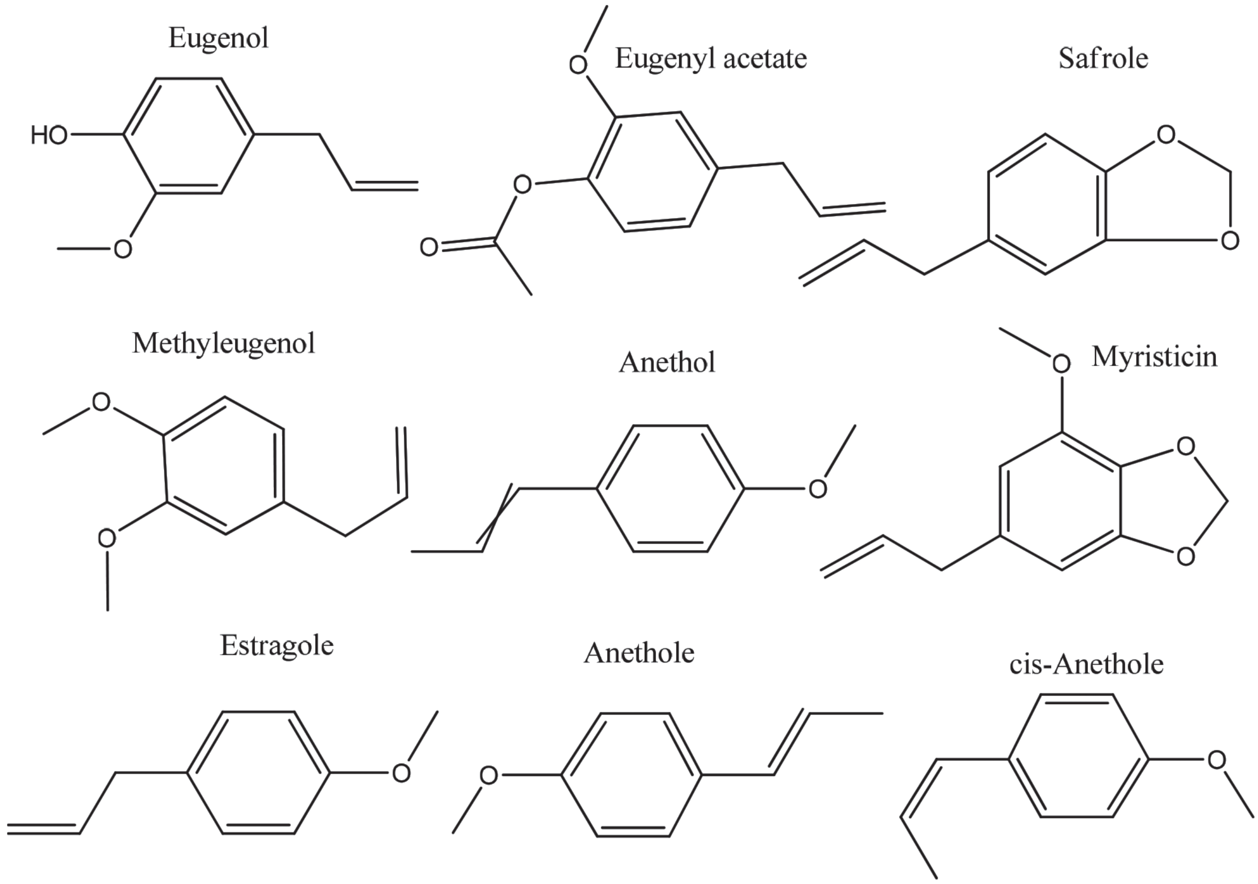

Figure 4. Chemical structures of phenylpropanoids with bioherbicidal action.

shows the chemical structures of the phenylpropanoids with potential use for control of invasive plants.

5. Conclusion

For essential oils to have good phytotoxic activity, some factors such as chemical composition, concentration and host plants may be taken into account. Among the monoterpene allelochemicals we can highlight the 1,8 cineole, among the sesquiterpenes or β-caryophyllene and among phenylpropanoids, eugenol. On the other hand, one of the difficulties that can appear for the use in large scale of essential oils is the volatility of their components.

Acknowledgements

Oliveira MS (Process Number: 1662230) and Costa WA (Process Number: 1427204) thank CAPES for the doctorate scholarship.

http://dx.doi.org/10.5772/intechopen.74346

Author details

Mozaniel Santana de Oliveira[1]*, Wanessa Almeida da Costa[2], Priscila Nascimento Bezerra[1], Antonio Pedro da Silva Souza Filho[3] and Raul Nunes de Carvalho Junior[1,2]*

*Address all correspondence to: mozaniel.oliveira@yahoo.com.br and raulncj@ufpa.br

1 LABEX/FEA (Faculty of Food Engineering), Program of Post-Graduation in Food Science and Technology, Federal University of Para, Belém, Pará, Brazil

2 Program of Post-Graduation in Natural Resources Engineering, Federal University of Para, Belém, Pará, Brazil

3 Laboratory of Agro-industry, Embrapa Eastern Amazon, Belém, Pará, Brazil

References

[1] Poletti M, Omoto C. Resistência de Inimigos Naturais a Pesticidas. Rev Biotecnol Ciência e Desenvolv. 2003;**30**:1-17

[2] Norsworthy JK, Ward SM, Shaw DR, Llewellyn RS, Nichols RL, Webster TM, Bradley KW, Frisvold G, Powles SB, Burgos NR, Witt WW, Barrett M. Reducing the risks of herbicide resistance: Best management practices and recommendations. Weed Science [Internet]. Jan 20, 2012;**60**(SP1):31-62. DOI: http://www.bioone.org/doi/full/10.1614/WS-D-11-00155.1

[3] Devine MD, Shukla A. Altered target sites as a mechanism of herbicide resistance. Crop Protection [Internet]. Sep 2000;**19**(8-10):881-889. Available from: http://linkinghub.elsevier.com/retrieve/pii/S026121940000123X

[4] Souza Filho APS. In: da Silva Sousa Filho AP, editor. Ecologia química: A experiência brasileira. 1st ed. Belém, PA: Embrapa Amazônia Oriental, Belém; 2008. 150 p

[5] Santos JCF, Edilene GM, Marchi CS. In: de Miranda FVC, do Nascimento FE, de Oliveira JF, editors. Daninhas do Café. 1st ed. Planaltina, DF- Brazil: Empresa Brasileira de Pesquisa Agropecuária Embrapa Cerrados Ministério da Agricultura, Pecuária e Abastecimento; 2008

[6] Filho AJC, Santos LS, Guilhon GMSP, Moraes RPC, dos Santos RA, Filho AP da SS, Felizzola JF. Identified substances from the leaves of *Tephrosia cinerea* (Leguminoseae) crude extracts and their phytotoxic effects. International Journal of Life-Sciences Scientific Research [Internet]. Jul 6, 2017;**3**(4):1137-1141. Available from: http://ijlssr.com/currentissue/Tephrosia cinerea (Leguminoseae) Crude Leaves Extracts and their Phytotoxic Effects.pdf

[7] Pereira SG, Soares AM dos S, Guilhon G, Santos LS, Pacheco LC, Souza Filho AP da S. Phytotoxic potential of piperine and extracts from fruits of *Piper tuberculatum* Jaq. on Senna obtusifolia and *Mimosa pudica* plants. Allelopathy Journal 2016;**38**(1):91-102

[8] Bostan C, Butnariu M, Butu M, Ortan A, Butu A, Rodinoc S, Parvue C. Allelopathic effect of *Festuca rubra* on perennial grasses. Romanian Biotechnology Letters. 2013;**18**(2):8190-8196

[9] de Oliveira MS, da Costa WA, Pereira DS, Botelho JRS, de Alencar Menezes TO, de Aguiar Andrade EH, da Silva SHM, da Silva Sousa Filho AP, de Carvalho RN. Chemical composition and phytotoxic activity of clove (*Syzygium aromaticum*) essential oil obtained with supercritical CO_2. Journal of Supercritical Fluids [Internet]. 2016;**118**:185-193. DOI: http://dx.doi.org/10.1016/j.supflu.2016.08.010

[10] Batista C de CR, de Oliveira MS, Araújo ME, Rodrigues AMC, Botelho JRS, da Silva Souza Filho AP, Machado NT, Carvalho RN. Supercritical CO2 extraction of açaí (*Euterpe oleracea*) berry oil: Global yield, fatty acids, allelopathic activities, and determination of phenolic and anthocyanins total compounds in the residual pulp. Journal of Supercrit Fluids [Internet]. Jan 2016;**107**:364-369. DOI: http://dx.doi.org/10.1016/j.supflu.2015.10.006

[11] Latif S, Chiapusio G, Weston LA. Allelopathy and the role of allelochemicals in plant defence. In: Becard G, editor. Advances in Botanical Research [Internet]. 82nd ed. 2017;**82**: 19-54. Available from: https://www.sciencedirect.com/science/article/pii/S0065229616301203

[12] Pavlychenko TK, Harrington J. Competitive efficiency of weeds and cereal crops. Canadian Journal of Research. 1934;**10**:77-94

[13] Lucas CE. The ecological effects of external metabolites. Biological Reviews of the Cambridge Philosophical Society [Internet]. 1947;**22**(3):270-295. Available from: http://www.ncbi.nlm.nih.gov/pubmed/20253195

[14] Rice EL. Allelopathy – An update. The Botanical Review. 1979;**45**(1):15-109

[15] Rice EL. Allelopathy. In: Rice EL, editor. 2nd ed. New York: Academic Press; 1984. 422 p

[16] Lee IK, Monsi M. Ecological studies on Pinus densiflora forest. Effect of plant substances in the floristic composition of undergrowth. Bot Manager. 1963;**76**:400-413

[17] Stickney JS, Hoy PR. Toxic action of black walnut. Transactions of the Wisconsin State Horticultural Society. 1881;**11**:166-167

[18] Schreiner O, Reed HS. The production of deleterious excretions by roots. Bull Torrey Bot Club [Internet]. 1907 Jun;**34**(6):279-303. Available from: http://www.jstor.org/stable/2479157?origin=crossref

[19] Muller CH. Inhibitory terpenes volatilized from Salvia shrubs. Bulletin of the Torrey Botanical Club. 1965:38-45

[20] Bueno MR, Alves GS, Paula ADM, Cunha JPAR. Volumes de calda e adjuvante no controle de plantas daninhas com glyphosate. Planta Daninha [Internet]. 2013;**31**(3): 705-713 Available from: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0100-83582013000300022&lng=pt&nrm=iso&tlng=en

[21] Gazziero DLP. Misturas de agrotóxicos em tanque nas propriedades agrícolas do Brasil. Planta Daninha [Internet]. Mar 2015;**33**(1):83-92 Available from: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0100-83582015000100083&lng=pt&nrm=iso&tlng=en

[22] Ferreira E, Procópio S, Galon L, Franca A, Concenço G, Silva A, Aspiazu I, Silva A, Tironi S, Rocha PR. Manejo de plantas daninhas em cana-crua. Planta Daninha [Internet]. 2010 Dec;**28**(4):915-925 Available from: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0100-83582010000400025&lng=pt&tlng=pt

[23] Souza Filho AP, Alves S de M. Alelopa tia em ecossistema de pastagem cultivada [Internet]. 1st ed. Belém: Embrapa; 1998. 71 p. Available from: http://www.infoteca.cnptia.embrapa.br/handle/doc/388173

[24] Christoffoleti PJ, Victoria R, Filho S, Da CB. Resistência de planta s daninhas aos herbicidas. Planta Daninha. 1994;**12**(1990):13-20

[25] LeBaron HM, McFarland J. Herbicide resistance in weeds and crops. In: Society AC, editor. Herbicides – Current Research and Case Studies in Use [Internet]. InTech; 1990. pp. 336-352. Available from: http://www.intechopen.com/books/herbicides-current-research-and-case-studies-in-use/herbicide-resistant-weeds-the-technology-and-weed-management

[26] Spiassi A, Konopatzki MRS, Nóbrega LHP. Estratégias de manejo de plantas invasoras. Revista Varia Scientia Agrárias. [Internet]. 2010;**1**:177-188 Available from: http://e-revista.unioeste.br/index.php/variascientiaagraria/article/viewArticle/3493

[27] Putnam AR. Allelochemicals from plants as herbicides. Weed Science Society of America [Internet]. May 1, 1988;**2**(4):510-518 Available from: http://www.jstor.org/stable/3987390

[28] Macías FA, Molinillo JM, Varela RM, Galindo JC. Allelopathy – A natural alternative for weed control. Pest Management Science [Internet]. 2007 Apr;**63**(4):327-348. DOI: http://doi.wiley.com/10.1002/ps.1342

[29] Marichali A, Hosni K, Dallali S, Ouerghemmi S, Bel Hadj Ltaief H, Benzarti S, Kerkeni A, Sebei AH. Allelopathic effects of *Carum carvi* L. essential oil on germination and seedling growth of wheat, maize, flax and canary grass. Allelopathy Journal [Internet]. 2014;**34**(1):81-94. Available from: http://search.proquest.com/openview/1742af81c669e6bce54668881b849f28/1?pq-origsite=gscholar

[30] Grichi A, Nasr Z, Khouja ML. Phytotoxic effects of essential oil from *Eucalyptus lehmanii* against weeds and its possible use as a bioherbicide. Bulletin of Environment, Pharmacology and Life Sciences [Internet]. 2016;**5**(March):17-23. Available from: http://bepls.com/beplsmarch2016/4.pdf

[31] Atak M, Mavi K, Uremis I. Bio-Herbicidal Effects of oregano and rosemary essential oils on germination and seedling growth of bread wheat cultivars and weeds. Romanian Biotechnology Letters. 2015;**21**(1):11149-11159

[32] Romagni JG, Allen SN, Dayan FE. Allelopathic effects of volatile cineoles on two weedy plant species. Journal of Chemical Ecology. 2000;**26**(1):303-313

[33] Singh HP, Batish daizy R, Kaur S, Ramezani H, Kohli RK. Comparative phytotoxicity of four monoterpenes against *Cassia occidentalis*. Annals of Applied Biology [Internet]. Oct 2002;**141**(2):111-116. DOI: http://doi.wiley.com/10.1111/j.1744-7348.2002.tb00202.x

[34] Kordali S, Cakir A, Ozer H, Cakmakci R, Kesdek M, Mete E. Antifungal, phytotoxic and insecticidal properties of essential oil isolated from *Turkish Origanum* acutidens and its three components, carvacrol, thymol and p-cymene. Bioresource Technology [Internet]. Dec 2008;**99**(18):8788-8795. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0960852408003696

[35] Jassbi AR, Zamanizadehnajari S, Baldwin IT. Phytotoxic volatiles in the roots and shoots of *Artemisia tridentata* as detected by headspace solid-phase microextraction and gas chromatographic-mass spectrometry analysis. Journal of Chemical Ecology. 2010;**36**(12):1398-1407

[36] De Almeida LFR, Frei F, Mancini E, De Martino L, De Feo V. Phytotoxic activities of Mediterranean essential oils. Molecules. 2010;**15**(6):4309-4323

[37] Singh HP, Batish DR, Kaur S, Kohli RK, Arora K. Phytotoxicity of the volatile monoterpene citronellal against some weeds. Zeitschrift fur Naturforsch – Section C Journal of Biosciences 2006;**61**(5-6):334-340

[38] Batish DR, Singh HP, Setia N, Kaur S, KRK. Chemical composition and phytotoxicity of volatile essential oil from intact and fallen leaves of *Eucalyptus citriodora*. Zeitschrift fur Naturforsch – Section C Journal of Biosciences. 2006;**61**(7-8):465-471

[39] Kaur S, Singh HP, Mittal S, Batish DR, Kohli RK. Phytotoxic effects of volatile oil from *Artemisia scoparia* against weeds and its possible use as a bioherbicide. Industrial Crops and Products [Internet]. 2010;**32**(1):54-61. DOI: http://dx.doi.org/10.1016/j.indcrop.2010.03.007

[40] Kant MR, Bleeker PM, Wijk M Van, Schuurink RC, Haring MA. Chapter 14: Plant volatiles in defence. In: Advances in Botanical Research [Internet]. 1st ed. Elsevier Ltd.; 2009. pp. 613-666. DOI: http://dx.doi.org/10.1016/S0065-2296(09)51014-2

[41] Dudareva N, Klempien A, Muhlemann JK, Kaplan I. Biosynthesis, function and metabolic engineering of plant volatile organic compounds. New Phytologist [Internet]. Apr 2013;**198**(1):16-32. DOI: http://doi.wiley.com/10.1111/nph.12145

[42] Batish DR, Singh HP, Kaur M, Kohli RK, Singh S. Chemical characterization and phytotoxicity of volatile essential oil from leaves of *Anisomeles indica* (Lamiaceae). Biochemical Systematics and Ecology [Internet]. Apr 2012;**41**:104-109. DOI: http://dx.doi.org/10.1016/j.bse.2011.12.017

[43] Souza Filho APDS, de Vasconcelos MAM, Zoghbi MDGB, Cunha RL. Efeitos potencialmente alelopáticos dos óleos essenciais de *Piper hispidinervium* C. DC. e *Pogostemon heyneanus* Benth sobre plantas daninhas. Acta Amazonica [Internet]. 2009;**39**(2):389-395. Available from: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0044-59672009000200018&lng=pt&tlng=pt

[44] Asplund RO. Some quantitative aspects of the phytotoxicity of monoterpenes. Weed Science Society of America. 1969;**17**(4):454-455

[45] de Oliveira CM, Cardoso M das G, Figueiredo AC da S, de Carvalho MLM, Miranda CASF de, Marques Albuquerque LR, Lee Nelson D, de Souza Gomes M, Silva LF, de Andrade Santiago J, Teixeira ML, Brandão RM. Chemical composition and allelopathic activity of the essential oil from *Callistemon viminalis* (Myrtaceae) *Blossoms on Lettuce* (*Lactuca sativa* L.) seedlings. American Journal of Plant Sciences [Internet]. 2014;**5**(24):3551-3557. Available from: http://www.scirp.org/journal/PaperInformation.aspx?PaperID=51896

[46] Mancini E, Arnold NA, 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. Journal of Plant Interactions. 2009;**4**(4):253-259

[47] Ibrahim MA, Kainulainen P, Aflatuni A, Tiilikkala K, Holopainen JK. Insecticidal, repellent, antimicrobial activity and phytotoxicity of essential oils: With special reference to limonene and its suitability for control of insect pests. Agricultural and Food Science in Finland. 2001;**10**(April):243-259

[48] De Martino L, Mancini E, De Almeida LFR, De Feo V. The antigerminative activity of twenty-seven monoterpenes. Molecules. 2010;**15**(9):6630-6637

[49] Hiltpold I, Turlings TCJ. Belowground chemical signaling in maize: When simplicity rhymes with efficiency. Journal of Chemical Ecology [Internet]. May 29, 2008;**34**(5):628-635. Available from:. DOI: http://link.springer.com/10.1007/s10886-008-9467-6

[50] Kobaisy M, Tellez MR, Dayan FE, Duke SO. Phytotoxicity and volatile constituents from leaves of *Callicarpa japonica* Thunb. Phytochemistry [Internet]. 2002 Sep;**61**(1):37-40 Available from: http://linkinghub.elsevier.com/retrieve/pii/S0031942202002078

[51] Wang R, Peng S, Zeng R, Ding LW, Xu Z. Cloning, expression and wounding induction of p-caryophyllene synthèse gene from *Mikania micrantha* H. B. K. and allelopathie potential of ß-caryophyllene. Allelopathy Journal. 2009;**24**(1):35-44

[52] Verdeguer M, Blázquez MA, Boira H. Phytotoxic effects of Lantana camara, *Eucalyptus camaldulensis* and *Eriocephalus africanus* essential oils in weeds of Mediterranean summer crops. Biochemical Systematics and Ecology [Internet]. Oct 2009;**37**(4):362-369. DOI: http://dx.doi.org/10.1016/j.bse.2009.06.003

[53] Macías FA, Galindo JCG, Molinillo JMG, Cutler HG. Allelopathy: Chemistry and mode of action of allelochemicals [Internet]. In: Macías FA, Galindo JCG, Molinillo JMG, Cutler HG, editors. Allelopathy - Chemsitry and Mode of Action and Allelochemicals. New York, Washington, D.C: CRC Press, Taylor & Francis; 2003. 392 p. Available from: https://books.google.com.br/books/about/Allelopathy.html?id=B0937BBWXjQC&redir_esc=y

[54] Silva MP, Piazza LA, López D, López Rivilli MJ, Turco MD, Cantero JJ, Tourn MG, Scopel AL. Phytotoxic activity in *Flourensia campestris* and isolation of (−)-hamanasic acid A as its active principle compound. Phytochemistry [Internet]. 2012;**77**:140-148. DOI: http://dx.doi.org/10.1016/j.phytochem.2011.09.020

[55] Ahluwalia V, Sisodia R, Walia S, Sati OP, Kumar J, Kundu A. Chemical analysis of essential oils of *Eupatorium adenophorum* and their antimicrobial, antioxidant and phytotoxic properties. Journal of Pest Science (2004). 2014;**87**(2):341-349

[56] Mazzafera P. Efeito alelopático do extrato alcoólico do cravo-da-índia e eugenol. Revista Brasileira de Botânica [Internet]. Jun 2003;**26**(2):231-238 Available from: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0100-84042003000200011

[57] Bainard LD, Isman MB, Upadhyaya MK. Phytotoxicity of clove oil and its primary constituent eugenol and the role of leaf epicuticular wax in the susceptibility to these essential oils. Weed Science [Internet]. Oct 20, 2006;**54**(5):833-837 Available from: https://www.cambridge.org/core/product/identifier/S0043174500015599/type/journal_article

[58] Ajayi OE, Appel AG, Henry Y. Phytotoxicity of some essential oil components to cowpea (*Vigna unguiculata* (L.) Walp.) seeds. International Journal of Plant Biology & Research. 2014;**2**(4):2-9

[59] Cruz GS, Wanderley-Teixeira V, Oliveira J V., Correia AA, Breda MO, Alves TJ, Cunha FM, Teixeira AA, Dutra KA, Navarro DM. Bioactivity of *Piper hispidinervum* (Piperales: Piperaceae) and *Syzygium aromaticum* (Myrtales: Myrtaceae) oils, with or without formulated Bta on the biology and immunology of *Spodoptera frugiperda* (Lepidoptera: Noctuidae). Journal of Economic Entomology [Internet]. 2014;**107**(1):144-153. Available from: http://www.ncbi.nlm.nih.gov/pubmed/24665696

[60] Shreeya A, Batish DR, Singh HP. Research paper alleopathic effect of aromatic plants: Role of volatile. Journal of Global Biosciences 2016;**5**(7):4386-4395

[61] Rolli E, Marieschi M, Maietti S, Sacchetti G, Bruni R. Comparative phytotoxicity of 25 essential oils on pre- and post-emergence development of *Solanum lycopersicum* L.: A multivariate approach. Industrial Crops and Products [Internet]. 2014;**60**:280-90. DOI: http://dx.doi.org/10.1016/j.indcrop.2014.06.021

[62] Andrés MF, Rossa GE, Cassel E, Vargas RMF, Santana O, Díaz CE, González-Coloma A. Biocidal effects of *Piper hispidinervum* (Piperaceae) essential oil and synergism among its main components. Food and Chemical Toxicology [Internet]. 2017;**109**:1086-1092. DOI: http://dx.doi.org/10.1016/j.fct.2017.04.017

[63] Meepagala KM, Sturtz G, Wedge DE, Schrader KK, Duke SO. Phytotoxic and antifungal compounds from two Apiaceae species, *Lomatium californicum* and *Ligusticum hultenii*, rich sources of Z-ligustilide and apiol, respectively. Journal of Chemical Ecology. 2005;**31**(7):1567-1578

[64] Vasilakoglou I, Dhima K, Paschalidis K, Ritzoulis C. Herbicidal potential on *Lolium rigidum* of nineteen major essential oil components and their synergy. Journal of Essential Oil Research. 2013;**25**(1):1-10