REVIEW

Potential role of *Eucalyptus* spp. and *Acacia* spp. allelochemicals in weed management

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Received: 3 May 2020; Accepted: 28 May 2020; doi:10.4067/S0718-58392020000300452

ABSTRACT

Eucalyptus spp. and *Acacia* spp. have been reported as major invaders in several regions and Mediterranean climates. It has been documented that *E. globulus* and *E. camaldulensis* can serve as resources of allelochemicals, which can be used as tools of control strategy of noxious weed species infesting the agricultural areas of the Mediterranean region. Additionally, the remarkable allelopathy potential of *A. dealbata* Link against various weed species has been highlighted in many recent studies. There is also evidence that other species belonging to *Acacia* spp. can suppress the native vegetation, including weeds, due to their allelopathic potential. However, allelochemical extracts from different plant tissues seem variable in terms of their effects on various species germination and growth parameters. Furthermore, the effectiveness of the allelochemicals in weed management is also a matter of choosing the most appropriate application rate at any case. In the present review, aspects of the potential role of *Eucalyptus* spp. and *Acacia* spp. allelochemicals in weed management were discussed. Further research is needed in order to optimize the use of such allelochemicals produced by invasive plants in the Mediterranean region in both organic and sustainable agriculture systems.

Key words: *Acacia* spp., allelopathy, *Eucalyptus* spp., invasive, weed management.

INTRODUCTION

Invasive plants have the potential to affect the structure of plant communities globally since they are among the most ubiquitous invasive organisms (Callaway et al., 2004; Arianoutsou et al., 2010). Most invasive plants have been introduced as bioenergy, ornamental or medicinal crops (Williamson, 1996), while some species have been introduced by accident (Newsome and Noble, 1986). The biological impact of plant invasions on flora diversity and ecosystem functions has been highlighted as an objective of extended research (Jackson et al., 2002; Wolfe and Klironomos, 2005; Vila et al., 2010; Hulme et al., 2013).

The pressure on native species is partially attributed not only to direct resource competition but also to the allelopathic potential of plant invaders (Hierro and Callaway, 2003; Levine et al., 2003; Hulme, 2007). Allelopathy is a biological phenomenon through which some plants release organic compounds known as allelochemicals from plant roots, stems, flowers, and leaves tissues to influence growth, survival and reproduction of neighboring plants (Ben Ghnaya et al., 2016). Allelochemicals consist of a variety of organic compounds such as simple polysaccharides, amino acids, organic acids and phenolic compounds (Inderjit and Duke, 2003). Allelopathic compounds have been reported to reduce seed germination, growth and establishment of surrounding plants (Fan et al., 1997; Wang et al., 2014). Although many of the plant invaders are not dominant in their natural habitat, they can become strong competitors of the plant species of the invaded ecosystem and that can be related to their allelochemical potential (Callaway 2000; Orr et al., 2005).

Weed control is mainly dependent on herbicides whose increased use is associated with issues such as evolvement of weed resistance to herbicides, crop injury, soil and water pollution, toxicity patterns to non-target organisms and concerns for human health (Li et al., 2003; Meksawat and Pornprom, 2010; Pot et al., 2011; Heap, 2014). Given that as a fact, weed scientists seek for alternative weed management practices less reliant on herbicides (Hiltbrunner et al., 2007; Kanatas et al., 2020). The allelopathic effects of invasive species on growth and development of native species, including noxious weed species, have been reported and set an interesting area of research regarding weed management efforts (Ben Ghnaya et al., 2016). The main objective of the current literature review was to point out the potential role of allelochemicals produced by invasive species in the Mediterranean region on developing more efficient and eco-friendly weed management practices.

ALLELOPATHIC EFFECTS OF *EUCALYPTUS* SPP. ON WEEDS

Allelopathic effects of *Eucalyptus globulus* Labill. on weeds

Eucalyptus spp. (*Myrtaceae*) are plant species widely used for the production of wood but they also have ability to suppress the establishment of understory native plants, including noxious weed species, under the dry climatic conditions of the Mediterranean regions (Almeida and Freitas, 2006; Giardina et al., 2007). This is partially attributed to phenolic and volatile compounds contained in the leaf tissues of the plant invaders and act as allelochemicals against the native vegetation (Al-Naib and Al-Mousawi, 1976; May and Ash, 1990). The presence of several terpenes which act as allelochemicals such as 1,8-cineol, limonene, α- and β-pinene has been also reported in *Eucalyptus* spp. (Muller et al., 1964). The two most widespread species in the world are *E. globulus* Labill. and *E. camaldulensis* Dehnh. (Andreu et al., 2009). *Eucalyptus globulus* has invaded into Mediterranean countries such as Spain, Italy and Greece (Sanz-Elorza et al., 2001; Giardina et al., 2007; Galanos, 2015). The species *E. camaldulensis* has also been recognized as invader in Spain, Portugal, Greece and Italy (Sanz-Elorza et al., 2001; Almeida and Freitas, 2006; Arianoutsou et al., 2010; Lazzaro et al., 2014).

It has been reported that leachates as derived from *E. globulus* fresh leaves reduced the resprouting ability of the sedge *Cyperus rotundus* L. by 57%-68% when applied at the concentrations of 20% (w/v) and 40% (w/v) whereas the corresponding reduction in resprouting of the noxious perennial grass *Cynodon dactylon* (L.) Pers. ranged between 82% and 89% (Babu and Kandasamy, 1997). Rhizomes of *C. dactylon* can lose up to 60% of their total weight due to the incorporation of *E. globulus* leaves in the soil at a rate of 100 g kg^{-1} whereas the corresponding reduction of foliage dry weight can reach the level of 64% (El-Rokiek et al., 2011). In another study, *E. globulus* essential oils reduced growth of *C. dactylon* by 66% when applied at 25% (v/v) concentration of extract whereas in higher concentrations complete inhibition of germination was noted (Daneshmandi and Azizi, 2009). Regarding annual weeds, Azizi and Fuji (2006) noticed that *E. globulus* essential oils applied at 0.2% (v/v) concentration reduced the germination of *Amaranthus retroflexus* L. by 80% and the germination of *Portulaca oleracea* L. by 90% when applied at 0.5% (v/v) concentration as compared to the control treatment. In the study of Rassaeifar et al. (2013), the application of *E. globulus* essential oil at 5 nL mL^{-1} (v/v) resulted in 50% lower germination percentage and approximately 39% lower radicle length and plant height of *Amaranthus blitoides* S. Watson as compared to the control treatment. The number of branches produced by *Echinochloa colona* (L.) Link can be reduced by 59% if *E. globulus* dry leaves are mixed within the soil profiles whereas the reduction of total plants' fresh weight has been recorded at 66% (El-Rokiek et al., 2011). A remarkable question is if *E. globulus* allelochemicals can surpass the effectiveness of a commonly used soil-active herbicide. The findings of Puig et al. (2013) revealed that incorporating *E. globulus* leaves as green manure into the soil profile at 2% (w/w) concentration results in approximately the same level of control of the perennial weed *Convolvulus arvensis* L. as compared to the case where *S*-metolachlor was applied at 960 g ai ha^{-1}. The same authors demonstrated that *E. globulus* green manure at 1% (w/w) reduced the density of broadleaves by 35% in comparison to the control treatment whereas the total grass weeds' density was by almost 54% lower as compared to the value recorded under the control treatment (Puig et al., 2013). In the study of Souto et al. (2001), soil bioassays revealed the allelopathic effects of *E. globulus* on the growth of *Lactuca sativa* L., *Dactylis glomerata* L. and *Trifolium repens* L. under the soil and climatic conditions of Mediterranean region. As suggested by Puig et al. (2018), green manure by *E. globulus* could be also exploited due to its allelopathic potential.

Allelopathic effects of *Eucalyptus camaldulensis* Dehnh. on weeds

In the greenhouse experiment of Del Moral and Muller (1970) it was noticed that covering the soil of the pans with 4-5 layers of leaves of *E. camaldulensis* can reduce dry weight of *Bromus rigidus* Roth, *B. hordeaceus* L. and *Avena fatua* L. by 24%, 30% and 48%, respectively, as compared to the case where the soil was left uncovered. In a more recent study it was noted that applying aqueous leaf extracts of *E. camaldulensis* at 20 g L^{-1} resulted in 53% and 67% lower percentage of seed germination for the perennial species *Rhaponticum repens* (L.) Hidalgo and *Plantago lanceolata* L., respectively, as compared to the control treatment (Dadkhah and Asaadi, 2010). Verdeguer et al. (2009) indicated that applying *E. camaldulensis* essential oils at various concentrations results in zero germination percentage for the annual species *Amaranthus hybridus* L. and *P. oleracea*. The same researchers did also obtain similar results for the herbicidal effects of the essential oils as derived from two other invasive species *Lantana camara* L. and *Eriocephalus africanus* L. on the annual weed species mentioned above (Verdeguer et al., 2009). Foliar water extracts of *E. camaldulensis* at 10 and 20 g L^{-1} reduced *P. oleracea* seed vigor by 48% and 66%, respectively, as compared to the control treatment whereas the highest concentration of the two resulted in 66% lower root and shoot length in comparison to the control treatment (Dadkhah, 2013). The foliar aqueous extracts of *E. camaldulenis* were also effective against *Carthamus oxyacantha* M. Bieb. since their application at 150 g L^{-1} resulted in 64% lower seedling length and 79% lower germination percentage as compared to the control treatment in the study of Khan et al. (2004). Similar observations were reported from the same authors regarding the herbicidal effects of another invasive species, *Prosopis juliflora* (Sw.) DC. foliar water extracts on germination percentage and seedling length of *A. fatua* (Khan et al., 2004).

Regarding the allelochemical potential of another species belonging to *Eucalyptus* spp., essential oil derived from *E. citriodora* Hook. tissues completely diminished seed germination percentage, seed vigor, radicle length and plummule length of *Parthenium hysterophorus* L. at any concentration applied in the study of Kohli et al. (1998). Complete control of the same weed species has been recorded 2 wk after treatment with *E. citriodora* essential oils at 75 and 100 µL mL^{-1} (Singh et al., 2005). Aquaeous extracts as derived from fresh leaves of *E. citriodora* reduced *A. fatua* root length by 60% when applied at 10% (v/v) concentration in comparison to the control treatment in the study of El-Rokiek and Eid (2009) and were more efficient than extracts derived from dry leaves.

ALLELOPATHIC EFFECTS OF *ACACIA* SPP. ON WEEDS

Allelopathic effects of *Acacia dealbata* Link on weeds

The genus *Acacia* spp. belongs to the botanical family of *Mimosaceae* and there are over 1300 species of *Acacia* spp. found throughout the world. Almost 1000 of them have been found in Australia whereas 144 species have been noticed in Africa, up to 89 species in Asia, and over 180 species in North and South America (Lorenzo et al., 2010a). More than 20 *Acacia* species have been confirmed as invasive at global range including Europe and the Medittarenean region (Lorenzo and Rodríguez-Echeverría, 2015). The study of Lorenzo et al. (2010b) indicated the species *A. dealbata* Link, *A. melanoxylon* R.Br., *A. longifolia* (Andrews) Willd., *A. retinodes* (Schltdl.), *A. saligna* (Labill.) H.L. Wendl., *A. mearnsii* De Wild. and *A. pycnantha* Benth. as the most dominant invaders in Italy, Portugal and Spain.

Of the species mentioned, *A. dealbata*, a tree that is widely naturalized in Atlantic and Mediterranean climates, has been indicated as the most frequent invader (Sheppard et al., 2006). The invasion of *A. dealbata* leaded to the limitation of eight native weed species as reported in the study of Lorenzo et al. (2012) and this outcome was mainly attributed to the allelopathic potential of the invader against the native vegetation. Such findings point out the need to investigate if the allelochemicals of *Acacia* spp. can be used for weed management purposes. There is evidence that *A. dealbata* leachates produced during the flowering period can affect germination and growth of understory native plants under the soil and climatic conditions of the Mediterranean region (Carballeira and Reigosa, 1999). Lorenzo et al. (2010b) also noticed that net photosynthesis of weeds belonging to the genus *Dicranum* spp. were significantly affected by leachates and macerates of *A. dealbata*. The leaves of *A. dealbata* can be incorporated as green manure into the soil and reduce the density of *P. oleracea* by approximately 51% when applied at the concentration of 1.5% (w/w) (Souza-Alonso et al., 2020). Similar observations have been made regarding the effects of *A. dealbata* allelochemicals on the respiration rates of noxious broadleaf weed species *Hedera hibernica* G. Kirchn. Bean. Souza-Alonso et al. (2020) also recommended that for a fraction of grass weeds, their density might be reduced by 46% if green manure from *A. dealbata* leaves and branches is incorporated into the soil profile at concentration of 3.0% (w/w). *Acacia* spp. had negative allelopathic effects on the growth of *L. sativa*, *D. glomerata*, and *T. repens* (Souto et al., 2001).

Methyl cinnamate is a compound found in the flowers of *A. dealbata* and other plants (Khanh et al., 2008) and has shown its herbicidal effects on *Lolium rigidum* Gaudin with its application reducing guaiacol peroxidase activity up to 57% and also inhibiting early stem and radicle growth of *L. rigidum* by 76% and 87%, respectively (Lorenzo et al., 2020). Methyl cinnamate can also significantly reduce *L. rigidum* seed germination and root length when applied at 640 nL cm^{-3} (Vasilakoglou et al., 2013). Given that *L. rigidum* is a noxious weed species infesting cereal crops with remarkable ability to evolve multiple herbicide patterns to up to 14 different modes of action, the use of allelochemical extracts from plants pose as an alternative and attractive option for its control (Adler and Chase, 2007; Heap, 2014; Travlos et al., 2018).

Allelopathic effects of other species belonging to *Acacia* spp. on weeds

Regarding the allelopathic effects of other invasive species belonging to *Acacia* spp. on weeds, extended research has been carried out during the last two decades. *Acacia melanoxylon* is a versatile tree considered as invasive especially relevant in Portugal and Spain (Knapic et al., 2006). There is evidence that the decomposition of *A. melanoxylon* in the soil environment inhibit germination of understory native plants and the inhibitory effects are even more obvious in the growth of the plants exhibited to the allelochemicals of the invader (González et al., 1995). In addition, the findings of a more recent study have established the possible herbicidal potential of *A. melanoxylon* allelochemicals since it was revealed that flower aqueous extracts at concentrations of 25% and 50% can reduce seed germination of *Lolium perenne* by 68% and 96%, respectively (Hussain et al., 2011). The same authors demonstrated that phyllode water extracts of *A. melanoxylon* at the concentration of 100% can increase the number of ungerminated seeds by 80% (Hussain et al., 2011). Regarding the herbicidal potential of other species, it was shown that radicle length of perennial grass weed species *Eragrostis curvula* (Schrad.) Nees was by 44% and 74% reduced when treated with 10 and 20 g L^{-1} of *A. mearnsii* aqueous leaves extracts as compared to the control treatment in the study of Fatunbi et al. (2009).

Furthermore, there is evidence that *A. saligna* flower methanol extracts reduce *Hordeum murinum* L. germination by 56%-87% when applied at 5 and 10 g L^{-1} as compared to control treatments whereas the corresponding effect of methanol leaf extracts on this monocotyledonous species' seed germination can reach 75% (Abd El Gawad and El-Amier, 2015). It was also reported that *A. mearnsii* root water extracts can reduce radicle length of *E. curvula* up to 77% when applied at 40 g L^{-1} (Fatunbi et al., 2009). For the case of *A. longifolia*, there is evidence about its herbicidal effects on weeds since its leaves can be incorporated as green manure into the soil profile and reduce total weed density by nearly 20% when applied at a concentration of 3% (w/w) (Souza-Alonso et al., 2020). Other recent findings also indicated that the presence of *A. saligna* under the field conditions of Nile Delta Coast of Egypt can reduce the density of *Bromus diandrus*, *Rumex pictus* and *Aegilops bicornis* while aqueous flower and leaf extracts have inhibitory effects on shoot and root lengths of *H. murinum* (Abd El Gawad and El-Amier, 2015). In Italy, the gradual disappearance of *Bromus madritensis*, *Hypochaeris glabra*, *Senecio lividus* and *Galium divaricatum* was attributed to *A. pycantha* invasion whereas other scientists reported that aqueous extracts as derived from *A. retinodes* flowers can reduce the germination of the broadleaf weed species *Carrichtera annua* more than 30% if applied at 100% concentration (Dana and Domingo, 2006; Lazzaro et al., 2015).

Nevertheless, it has to be noted that despite the proven phytotoxicity *in vitro*, recent work casts some doubt on the allelopathic capacity under natural conditions. For instance, Lorenzo et al. (2016) revealed that the bioactivity of tested compounds was not the same under different conditions and methodologies. Yannelli et al. (2020) suggested that chemically-induced signals may facilitate *Acacia* spp. establishment, regardless of whether they had overlapping native ranges and consequently it is not valid *per se* that the release of allelopathic compounds by alien species inhibits the growth of native plants.

CONCLUSIONS

This review was focused on the potential utility of *Eucalyptus* spp. and *Acacia* spp. allelochemicals on weed management. Species of both genera have been reported as major invaders in Mediterranean and other regions. It is well established that *E. globulus* and *E. camaldulensis* can serve as a valuable resource of allelochemicals which can be used for the control of noxious weed species infesting the agricultural areas of the Mediterranean region. The remarkable allelopathic potential of *A. dealbata* against various weed species has been highlighted in many recent studies, even if the bioactivity is not the same under the same conditions and methodologies. There is also evidence that other species belonging to *Acacia* spp.

can suppress the native vegetation, including weeds, due their allelopathic potential. However, allelochemical extracts from different plant tissues seem can be within a wide range in terms of their effects on various species germination and growth parameters. Furthermore, the effectiveness of the allelochemicals in weed management is also a matter of choosing the most appropriate application rate at any case. Another parameter that needs to be investigated is which are the allelochemicals most related to the control of each weed species. Further research is needed in order to optimize the use of such allelochemicals produced by invasive plants in the Mediterranean region in terms of weed management in both organic and sustainable agriculture systems.

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