https://doi.org/10.26651/allelo.j/2021-53-1-1-1324 0971-4693/94 Euro 20.00
Allelopathy Journal 53 (1): 15-22 (May, 2021) *International Allelopathy Foundation* 2021
Table: -, Figs: 2

Allelopathic plants 29: *Eupatorium adenophorum* Sprengel

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(Received in revised form: February 20, 2021)

CONTENTS

ABSTRACT

Eupatorium adenophorum is worldwide-spread invasive plant. This review focussed on unique metabolite, Euptox A, released by this plant and its importance in invasion, use and control. Based on previous literature, it is concluded that the mechanism of the invader's success has a close relationship with a special compound, Euptox A. Its release and degradation mostly determines the spread of *E. adenophorum*. Besides, the control and use of this invasive species should consider the toxicity of Euptox A. This review suggests that the secondary metabolite, Euptox A, might be a key in controlling and using this invasive plant. This review will increase our knowledge of the role of a natural chemical in biological invasion.

Key words: Allelopathy, *Eupatorium adenophorum*, Euptox A, invasive plant, natural product, soil microbe

1. INTRODUCTION

Eupatorium adenophorum Sprengel (syn. *Ageratina adenophora*; Compositae), a perennial herb or subshrub, is a notorious invasive weed (Fig. 1). It is native to Mexico and Costa Rica but distributed in > 30 countries including China, India, Sri Lanka, Jamaica, Australia and New Zealand (8). It has great impacts on local ecosystems and agriculture etc. and is severe threats to human and animal health. Its invasion significantly decreases species diversity and also suppressed the growth of native plant communities (4,8). This

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alien plant has caused millions of dollars of economic losses in China (47). Besides, its invasion also increases forest fire (42). Many studies and several hypotheses have been proposed to explain its invasion mechanisms (6,7,45,59). To prevent and control its spread is main challenge (18,55). This review aimed to reveal the mechanisms of *E. adenophorum*'s successful invasion and the eco-friendly control of its invasion.

Figure 1. Morphological characteristics of *Eupatorium adenophorum*: (a) Individual plants growing under evergreen forest, (b) A typical *E. adenophorum* population from roadside in Panzhihua, Sichuan Province, Southwest China. (Photograph: Xunzhi Zhu).

2. MORPHOLOGY AND HABITS

Eupatorium adenophorum is a perennial herb with erect purplish stems, 30-200 cm tall, branching starts from the stem base. The leaves are mostly lozenge and the flowers are white and grow on the top of the branches. Each adult plant produces up to 100,000 seeds per year. The seeds are light (25,000 seeds per g) and have white crowns. The seeds can spread over long distances by wind, water, human's activities, live stocks and vehicles. Its extensive adaptability and stress resistance are the main reasons for its spread. Its grows on road sides, natural grasslands or in shaded forests. It is adaptable to stone cracks, and barren soil (39). *E. adenophorum* is a thermophilic and hygrophilous plant. Its seed germination requires light and seedlings are shade tolerant (25). The slope direction and gradient affects its invasion (28). It blossoms early and has long vegetative growth stage than native plants, giving it strong competitive ability. It allocates more biomass to shoot, which increases the light capture (9). *E. adenophorum* has higher leaf area and leaf longevity than native species. These morphological characters makes its invasion successful (43).

3. PHYTOCHEMICALS

The chemical composition of *E. adenophorum* roots, stems, leaves and flowers has been determined including its allelopathic potential, insecticidal activities of its substances. Its chemical compounds include (mono-, sesqui-, di-, and tri-) terpenoids, steroids,

phenylpropanoids, flavonoids, coumarins, sterols and alkaloids (19,49). These substances possess antioxidant and insecticidal, antimicrobial and plant growth regulating activities (49). In essential oils from its inflorescences and roots, sesquiterpenes were dominant, while sesquiterpenes (34.3 %) and monoterpenes (32.5 %) were main components of root oils (1). Its leaf volatiles, contains α-phellandrene, camphene, ρ-cymene, α-pinene and limonene (56). Its compounds have bioactivities. Thymol derivatives have antibacterial activity (5), new monoterpene and sesquiterpene showed *in-vitro* bacteriostatic activity against Gram-positive bacteria (29). Phenolics in *E. adenophorum* roots were inhibitory to seed germination and seedling growth of *Arabidopsis thaliana* (60).

4. ALLELOPATHY RESEARCH

4.1 Allelopathic effects

Eupatorium adenophorum adversely affects the growth and diversity of native plant communities. The "novel weapon hypothesis" (3) explains the mechanism of successful *E. adenophorum* invasion through release of allelopathic substances that inhibited and excluded native plants. It invasiveness is closed related with its secondary metabolites. The chloroform extract of its shoot inhibits the seed germination and seedling growth of onion (*Allium cepa*), radish (*Raphanus sativus*) and cucumber (*Cucumis sativus*) (2). The aqueous extracts from the leaves significantly inhibits the seedling growth of *Amaranthus caudatus* and *Vigna unguiculata* (36). It also has negative effects on spore germination and gametophyte development of *Neocheiropteris palmatopedata*, an endangered fern species in China (57). The allelopathic effects of different parts of *E. adenophorum* vary, leaves were more allelopathic than roots and stems (58). Yang *et al.* (2006) isolated and purified two main allelopathic compounds [9-Oxo-10,11-dehydroageraphorone (DTD, later named Euptox A) and 9β-Hydroxy ageraphorone (HHO)] from water extracts of *E. adenophorum* stems and leaves (51) . These allelopathic compounds attack native plants, can cause changes in malondialdehyde (MDA), peroxidase and the activities of other antioxidant enzymes in root cells of rice (*Oryza sativa*). Besides they lead to changes in physiological and biochemical indexes such as abscisic acid (ABA), indole-3-acetic acid (IAA) and other hormones (51,52). Additionally, these two allelochemicals can also induce changes in the anatomical structures of meristem and cortical parenchyma cells on the apical tip of rice (50). They are found only in *E. adenophorum* and considered to be newly identified compounds. Yang *et al*. (53) isolated and identified Euptox A from its root (53).

Euptox A produced by *E. adenophorum* not only inhibits the growth of native competitive plants, but also has insect repellent and antibacterial activity, which makes it a typical defence substance. Euptox A had strong anti-feeding activity against the herbivorous insect *Helicoverpa armigera* (EC50 = 2.57 g/cm^2) (38). The *E. adenophorum* oil extracted from its leaves is inhibitory to mycelia growth of plant pathogenic fungus *Phytophthora capsici*, (27). He *et al*. (12) found that *E. adenophorum* induces the apoptosis and autophagy on goat liver cells through the mitochondrial PI3K/Akt/mTOR-mediated pathway (12). The presence of Euptox A in *E. adenophorum* made it toxic to livestock, which reduces its grazing by livestock (11).

4.2 Interactions of allelochemicals and soil microbes

Alien invasive plants can release secondary metabolites into the soil environment through stem and leaf leachates and root exudates, which affects the soil microorganisms owing to the lack of shared evolutionary history (10). The secondary metabolites of *E. adenophorum* in the soil changes the composition and quantity of microbial community, soil enzyme activity and soil nutrients in the invaded area (32). The secondary metabolites secreted by invasive *E. adenophorum* change the soil bacterial community, its composition and diversity (40,46,62). This affects the growth and development of native plants, thus promoting the expansion of *E. adenophorum* and the establishment of its population (30,31). The responses of soil bacteria communities to plant secondary metabolites also depend on soil type (61). The invader can increase the beneficial microbes to improve the soil nutrients and form a suitable soil microenvironment. Allelochemicals of *E. adenophorum* can promote the growth of *Bacillus megaterium*, an efficient phosphorous-solubilizing bacterium, leading to improvement in the available phosphorus contents of the soil.

Soil physical adsorption, chemical transformation and biodegradation can reduce or even eliminate the allelopathic effects of alien species on native plants. Our research found that soil microorganisms can reduce or eliminate the chemical competition between the invasive species and native plants (63). Euptox A can rapidly be degraded by microorganisms (20), while the levels of Di-n-octyl phthalate, increases quickly, which suggests that this compound is the product of allelochemical degradation (63). Some allelopathic compounds are inhibitory to some plants even at very low concentrations (54). Liao *et al*. (24) isolated three strains of bacteria (*Stenotrophmonas* sp., *Pseudomonas* sp. and *Klebsiella* sp.,) with the ability to degrade Euptox A. Li *et al.* (21) also isolated two bacterial strains (*Arthrobacter* sp. and *Rhodococcus* sp.,) from the invasive and non-invasive soil of *E. adenophorum*. The *Arthrobacter* sp. strain caused better degradation of Euptox A than that of *Rhodococcus* sp. Strain (21).

5. APPLICATIONS OF ALLELOCHEMICALS

The *E. adenophorum* contains sesquiterpenes, steroids, triterpenes and flavonoids. The biological activities of these substances include anti-insect, antibacterial, antiviral activity and plant growth regulation. Euptox A is promising plant-based acaricidal agent and has strong toxicity against *Psoroptes cuniculi* and *Sarcoptes scabiei* (13,23,34). Euptox A also has significant anti-aphid activity on *Pseudoregma bambucicola* (33) and also can be used to develop antifungal agents (15). Euptox A has anti-cancer potential and can induce the apoptosis of HeLa cell (22). The *E. adenophorum* essential oil has antibacterial activity against *Arthrobacter protophormiae*, *Escherichia coli*, *Micrococcus luteus*, *Rhodococcus rhodochrous* and *Staphyloccocus aureus* (16). The *E. adenophorum* extract is inhibitory to Tobacco Mosaic Virus (TMV) (14). If Euptox A is used as biological agent, as natural pesticide, organic fungicide, or biological herbicide, however,safety of its release into the environment must be addressed. Bioengineering may be used to find bacterium that can degrade Euptox A safely and effectively.

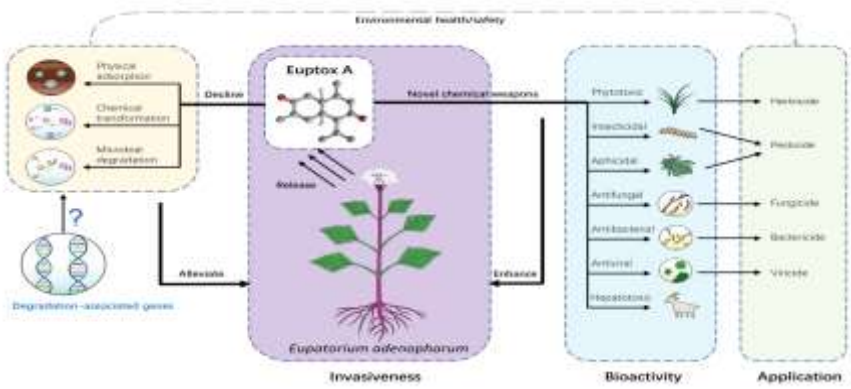

Figure 2. Multiple effects of Euptox A and its relationship with the invasion of *E. adenophorum*.

Euptox A released from *E. adenophorum* has multiple effects and its relationship with the invasiveness of this plant specie (Figure 2). Euptox A can act as a "novel chemical weapon" to facilitate its invasion by inhibiting the native plants. It is herbicidal, insecticidal, aphicidal, antifungal, antibacterial, antiviral, hence, it has potential to be developed as pesticide, fungicide, bactericide, and viricide. Besides, we found that microbes can degrade Euptox A to make *E. adenophorum* less invasive.

6. *E. ADENOPHORUM* BIOCONTROL

The main ways of preventing and controlling *E. adenophorum* growth are mechanical, chemical, and biological methods. A plant that is not sensitive to *E. adenophorum* allelochemicals can be used as an alternative control plant. The *Bidens pilosa*, also an alien plant is less hazardous than *E. adenophorum* and produces abundant seeds, hence, can be used to control this invasive weed. The allelochemicals of *E. adenophorum* in soil does not influence the seed germination and seedling growth of *B. pilosa* (44). Thus, *B. pilosa* can be grown in areas infested by *E. adenophorum.*

7. FUTURE RESEACH AREAS

(i). Identify the genes involved in microbial degradation of allelochemicals from invasive plants, conditions suitable for degradation and optimizing the bacteria degradation efficiency of allelochemicals for biological control of exotic plants.

(ii). Research on Euptox A to understand the mechanism of microbial degradation to control the *E. adenophorum*. This will expand and supplement the theory of biological invasion. Besides, the results will provide technical support to identify the bacteria capable of biodegrading the Euptox A.

8. CONCLUSIONS

Eupatorium adenophorum is an invasive allelopathic plant. The allelopathic potential mainly resulted from a small molecular-weight compound named Euptox A. This compundhave multiple bioactivities (phytotoxicity, antifungal and antibacterial activities and invasiveness). Euptox A may be used to develop ecofriendly pesticides (herbicide, pesticide, fungicide) and bactericide. Currently, researchers have isolated several microbial strains which can degrade Euptox A. This provided possibility to control the invasive plant *E. adenophorum* by biological agents. Future research might be done to finding the degradation-associated genes in microbes.

ACKNOWLEDGMENTS

This work was financially supported by the Program of Jiangsu Key Laboratory for the Research and Utilization of Plant Resources (JSPKLB201909), the Belt and Road Special Foundation of the State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering (2019491111), Open Research Fund of Zhejiang Tiantong Forest Ecosystem National Observation and Research Station (TTK201905), Hangzhou West Lake Scenic Area Science and Technology Development Project (2019-008).

Competing interests: Authors declare no competing interests.

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