

BIOLOGICAL SCIENCES

ROLE OF ALLELOPATHY IN THE ECOLOGICAL STRATEGY OF SOME INVASIVE ALIEN TREE SPECIES POSING A THREAT TO THE NATURAL FORESTS IN BULGARIA

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Abstract

In Bulgaria, studies of the allelopathic relationships between plants are mainly focused on agrophytocenoses, more specifically determination of allelopathic interference in the systems "crop - weed". The aim of the present study is, based on data from review of scientific publications and electronic databases, to assess the role of allelopathy in the ecological strategy of the main invasive alien tree species (IAS), representing the greatest threat to biodiversity in Bulgarian forests.

The object of study are the following IAS that invade forest habitats on the territory of Bulgaria and enter into competition with local plants: *Acer negundo* L., *Ailanthus altissima* (Mill.) Swingle, *Amorpha fruticosa* L., *Elaeagnus angustifolia* L., *Robinia pseudoacacia* L., *Fraxinus pennsylvanica* Marshall and *Morus alba* L. The assessment of the place of allelopathy in the ecological strategy of the IAS is based on the following criteria (main plant functional traits): *Juglone index*, *Tolerans of IAS to environmental conditions*, *Propagation by seeds*, *Vegetative propagation*, *Growth*, *Disease and pest resistance*.

The shareholding of allelopathy (*Aias*) compared to other criteria for all IAS is in the range 0.4-0.5, which means that allelopathy plays an equal role together with the other main criteria forming the ecological strategy of the species. Phytochemical activity can be manifested with different strength in the different stages of the invasion of the IAS in the forest communities with disturbed structure, thereby facilitating the manifestations and strengthening the effect of the impact of the remaining competitive plant functional traits of the species in its ecological strategy.

Keywords: invasive alien species, allelopathy, phytotoxins, forest communities, competition.

Introduction

Invasive alien species (IAS) are recognised for triggering various impacts, such as habitat modification, the alteration of community structure, and affecting ecosystem processes (Caramelo et al. 2021). One of the possible mechanisms of successful IAS introduction is explained by allelopathic interactions, when these species in one way or another secrete substances that suppress or, conversely, activate the vital activity of surrounding plants in the local phytocenosis (Nikolaeva et al. 2021). According to so called Novel Weapon Hypothesis, many IAS are successful invaders because they release allelopathic compounds that are highly suppressive to naïve competitors in invaded ranges but are relatively ineffective against competitors in their native range. (Ayub et al. 2020). For this reason research of allelopathic effects of IAS is important for their management because of their influence on native communities (Rafikova and Veselkin, 2022).

Zhang et al. (2021) conducted meta-analysis of 384 studies that measured allelopathic effects between plant species including invasive ones and concluded that overall, allelopathy reduced plant performance by 25%, but the variation in allelopathy was high. It depends of type of method affected the allelopathic effect (which is stronger in leave leachates and wicker in soil leachates), phylogenetic distance between species (it became more negative with increasing phylogenetic distance), plant origin (native plants suffered more from leachates of naturalised alien plants than from leachates of other native plants).

In Bulgaria, studies of the allelopathic relationships between plants are mainly focused on agrophytocenoses, more specifically determination of allelopathic interference in the systems "crop - weed" (Dimitrova, 2008) including investigations on invasive alien weeds like *Sorghum halepense* (L.) Perse. (Kalinova et al., 2012) and *Xanthium strumarium* L. (Nakova, 2004, Kalinova et al. 2012). According to Marinov-Serafimov et al. (2013) because of the selective nature of allelopathy, we should not expect that it alone could destroy all weeds in a typical agricultural setting, but it could function as an element of an overall weed control strategy.

The aim of the present study is, based on data from scientific publications, to assess the role of allelopathy in the ecological strategy of the main invasive alien tree species, representing the greatest threat to biodiversity in Bulgarian forests

Materials and methods

Glogov (2023) defines the following main invasive alien tree species that invade forest habitats on the territory of Bulgaria and enter into competition with local plants: *Acer negundo* L., *Ailanthus altissima* (Mill.) Swingle, *Amorpha fruticosa* L., *Elaeagnus angustifolia* L., *Gleditsia triacanthos* L., *Laburnum anagyroides* Medik., *Robinia pseudoacacia* L. The mentioned IAS are included in the List of Invasive Alien Species of Vascular Plants in Bulgaria (Petrova et al., 2013).

This literature review was conducted with an extensive search in physical library of Forest Research Institute-Bulgarian Academy of Sciences, and search engines in the Bulgarian libraries shared database

COBISS+, world electronic databases and scientific networking sites Web of Science, Scopus and Research gate, CABI. The keywords used in combination during the search were “allelopathy”, “invasive alien species”, “juglone index”, “phytotoxins”, latin and common names of the above mentioned woody species. At this stage *Gleditsia triacanthos* and *Laburnum anagyroides* are removed from the study due to the lack of data on their *juglone index* values. In their place, the present study included two alien tree species that pose a serious threat to natural regeneration in our riparian forests - *Fraxinus pennsylvanica* Marshall and *Morus alba* L. (Hinkov, 2023), but are not yet included in the official IAS list for Bulgaria. The span of the literature search was between November 01, 2023, and February 10,

2024. A total of 28 original articles were selected for inclusion in the review.

The assessment of the place of allelopathy in the ecological strategy of the IAS is based on the following criteria (main plant functional traits):

A- Juglone index.

The allelopathic potential of IAS was quantified by "juglone-index", which uses the known allelopathic ability of black walnut (*Juglans regia* L.) leaf extracts as a reference point.

The values of juglone index (I_j/x) for each woody species are according to the data of Csizsár (2009) obtained at higher concentration extract (5 g plant material extracted by 100 ml distilled water). The assessment of the allelopathic impact is according to the following scale (Table 1):

Table 1.

Scale of allelopathic impact		
Score	I_j/x	Level of allelopathic impact
5	$>0,9$	High
3	$0,6-0,9$	Medium
1	$<0,6$	Weak or absent

B- Tolerance of IAS to environmental conditions. Scores: 3 (Species is tolerant to any of the environmental factors); 2- tolerant within certain limits (e.g. tolerates some shading or is a xeromesophyte); 1- intolerant to the change of one or more environmental factors;

C- Propagation by seeds. Scores: 2- large amount of seeds and/or high germination; 1- small quantity of seeds and/or low germination;

D- Vegetative propagation. Scores: 2- strong, 1- weak;

E- Growth- 3- fast; 2-normal; 1- slow;

F- Disease and pest resistance. Scores: 2- the species is weakly attacked by pests and/or diseases, or if attacked, their impact is not fatal to its existence. 1- the species is vulnerable to one or more pests or diseases that can lead to the death of individuals and entire populations.

The shareholding of allelopathy (*Aias*) compared to other criteria for specific IAS is estimated according to the following formula:

$Aias = A/(B+C+D+E+F)$, where at

$Aias > 0.5$ - allelopathy plays a leading role in the ecological strategy of the species;

$Aias$ between 0.5 and 0.2 - allelopathy plays an equal role together with the other main criteria forming the ecological strategy of the species

$Aias < 0.2$ - allelopathy plays a smaller role than the other main criteria forming the ecological strategy of the species.

Results

Based on the data from the reviewed literature sources (mainly Digital library of CABI (2022) and the scientific publications cited there) for each of the target IAS, assessments were made according to the individual criteria (Table 2). The arguments for scores other than the maximum are presented in the comments.

Table 2.

The assessment of criteria (main plant functional traits) forming the ecological strategy of the IAS

IAS	Ij	A	B	C	D	E	F	Aias	Comments
<i>Acer negundo</i>	0.99	5	3	2	2	3	1	0.5	F=1- The species shows strong vulnerability to some pathogens such as <i>Verticillium albo-atrum</i> , which causes verticillium wilt
<i>Ailanthus altissima</i>	1.49	5	3	2	2	3	1	0.5	F=1- Insect pest <i>Eligma narcissus</i> is a serious defoliator of saplings. Seedlings mainly suffer from root rots (<i>Rhizoctonia</i> and <i>Fusarium</i> spp.), and are also susceptible to <i>Verticillium</i> wilt
<i>Amorpha fruticosa</i>	2.00	5	3	2	2	3	2	0.4	
<i>Elaeagnus angustifolia</i>	0.93	5	3	2	2	3	1	0.5	F=1- The species is susceptible to wilt caused by <i>Verticillium</i> , but also to canker and dieback caused by <i>Phomopsis elaeagni</i>
<i>Fraxinus pennsylvanica</i>	1.01	5	2	2	2	3	1	0,5	B=2-The species is somewhat demanding on soil conditions. On compacted and dry soils, some of its branches often dry out; F=1- Serious damages caused by fungus <i>Myco-sphaerella fraxinicola</i> and <i>Gloeosporium aridum</i> which causes premature defoliation
<i>Morus alba</i>	0.86	5	2	2	2	3	1	0,5	B=2- <i>M. alba</i> has some shade tolerance and is moderately tolerant of drought; F=1 The species is attacked by about 300 species of arthropod pests worldwide and some serious pathogens like <i>Fomes</i> spp., <i>Armillaria melea</i> , <i>Fusarium</i> sp. etc.
<i>Robinia pseudoacacia</i>	1.01	5	3	2	2	3	2	0,4	

For 2 of the IAS included in the study, the results show maximum values for all criteria, and for the rest, lower scores are observed only for the criterion F (Resistance to diseases and pests). The shareholding of allelopathy (*Aias*) compared to other criteria for all IAS is in the range 0.4-0.5, which means that allelopathy plays an equal role together with the other main criteria forming the ecological strategy of the species.

Discussion

According to Grime's theory on CSR-strategies of plants (Grime, 2006) all studied IAS are defined as "competitors" and their plant functional traits (the criteria evaluated above) play a key role in the competition between invasive and native species (Guo et al. 2023). Despite the high values of the *Juglone index*, at this stage it could not be said with certainty that allelopathy is a powerful enough IAS tool for impacting on native species and suppressing their development. Caramelo et al. (2021) report that in terms of phytochemistry at the present stage in different plant parts of *Ailanthus altissima*, 49 main compounds distributed by major classes were found as follows: 17 alkaloids (isolated mainly from the root bark); 18 terpenoids (mainly Stem bark, root bark, seeds, and fruits), including Ailantho-specific compounds such as Ailanthone, Ailantol, Ailantholide and Chapparin; 13 steroids (mainly from fruits) including Ailanthusterol A and B; 6 Flavonoids (from leaves); 7 Miscellaneous compounds like alcohols, coumarins etc. (from leaves and bark). But on the other hand, a number of studies also show a high phytochemical potential in many of the local tree and shrub species forming the natural dendrocenosis in the territory of the country (Stoyanova et al., 1994, Semerdjieva et al., 2023 etc.).

The range of allelopathic potential for the IAS could be similar to that documented for some native species from the same area (Pisula, Meiners, 2010). A study by Nikolaeva et al. (2021) shows that active substances contained in leaf litter *A. negundo*, have a selective inhibitory effect on the germination of seeds and the growth of seedlings of monocotyledonous and dicotyledonous plants. Another important finding of the same authors was that allelopathic effect of the fall is not a limiting factor for the germination of seeds of herbaceous plants of the above-ground cover of the studied plantation. Data from investigation of Rafikova and Veselkin (2022) do not support a hypothesis that allelopathy can explain the ability of *A. negundo* to influence native communities. Carter et al. (2017) assess the allelopathic effect of *Robinia pseudoacacia* in Northern Michigan Forests and concluded that this IAS likely exhibits increased allelopathy as relative density increases. Isolated individuals on a disturbed edge may not be able to produce allelopathic phenolic compounds in concentrations sufficient to alter species composition. The results from investigation of Krstin et al. (2019) demonstrate that *Amorpha fruticosa* phytotoxicity is dependent on both the plant species tested and leaf extract concentration, with higher concentration extracts having stronger phytotoxicity. Llinares et al. (1994) suggested that allelopathic chemicals in *Elaeagnus angustifolia* litter inhibit microbial nitrification and may result in considerable N-conservation on sites dominated by *E. angustifolia*. Investigating the effect of leaf extracts of *Morus alba*, Khalid et al. confirmed the strong allelopathic effect of the species and found that the dry leaves extract had more inhibitory effect than the fresh leaves extract. A similar study by Izotkin, Holenko (2020) proves the stronger allelopathic

activity of IAS *Fraxinus pensylvanica* compared to the native species *F. excelsior* L. The authors point out one of the weaknesses that arise in such studies as all discussed above: 1. They are done in a laboratory environment, and it is necessary for more accurate results to conduct the experiments in natural conditions; 2. The objectivity of the results also implies that, in parallel with the phytochemical activity of the specific IAS, the influence of all other factors forming the abiotic and biotic components of the forest phytocenoses should be taken into account.

Conclusions

At the current stage, the results of the study support the notion of the equal role of allelopathy in the cumulative effect of the impact of all competitive functional traits of IAS and thus confirms the ecological significance of allelopathy which promotes species coexistence via intransitive competition, modifications of direct interactions, and (co)evolution (Hierro, Callaway. 2021). Phytochemical activity can be manifested with different strength in the different stages of the invasion of the IAS in the forest communities with disturbed structure, thereby facilitating the manifestations and strengthening the effect of the impact of the remaining competitive plant functional traits of the species in its ecological strategy.

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