RESPONSE OF ALLELOCHEMICAL ACTIVITY OF SOLIDAGO TO DIFFERENT ACCEPTOR SPECIES EX SITU DURING VEGETATION STAGES

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Abstract

Allelopathy refers to the beneficial or harmful effects of one organism on another by the release of biochemical. In phytocommunities, the secondary plant metabolites have the allelochemical potential and suppress both seed germination and seedling growth playing an important role in determining initial establishment and subsequent spread of invasive species.

The content of phenolic compounds was estimated to be different in aqueous extracts of S. canadensis due to their dissimilar accumulation in plant parts (root and shoot), growth stage and leachate concentration. As phenolics affect various physiological processes, thus altering the physiological and growth patterns of plants, the revealed TPC exhibited different allelopathic potential of S. canadensis extracts. Thus, the TPC and CCU data for the researched acceptor species suggested that S. canadensis might provide the considerably allelopathic influence on the species diversity or local out-compete of the native plants in new habitats.

Key words: allelopathy, germination, goldenrod, phenolics, phytotoxicity.

INTRODUCTION

Allelopathy is an action of natural bioactive chemicals produced by plants to other life. Allelopathy is already a long-standing conception, starting from the definition of Dr. Hans Molisch in 1937. Allelochemicals are released from plant parts by leaching, root exudation, volatilization, residue decomposition and other processes in both natural and anthropogenic systems. They affect the neighbouring
species of native flora and other organisms (Baležentienė, Renčo, 2014; Sampietro, Vattuone, 2006).

Recently, allelopathy is getting new significance in explanation of species invasiveness. Allelopathy is not a unifying theory of plant interactions, nor do we espouse the view that allelopathy is the dominant way that plants interact, but we argue that non-resource mechanisms should be discussed as a potential mechanism for explaining the remarkable success of some invasive species (Blumenthal, 2005). However, hypothesis for the astonishing success of many exotics, as community invaders, relative to their importance in their native communities is that they have escaped the natural enemies that control their population growth – the ‘natural enemies hypothesis’. Moreover, many of the worldwide most common and ecologically devastating exotic invaders are not as successful at their native ranges. Nonetheless, currently someone considered that the biochemical compounds emerged by the invader have harmful effects on the species of the recipient plant community, i.e., allelopathy. This non-resource mechanism should be considered as potential tool for explaining the significant success of some invasive species. In 1959, Fraenkel recognized that the secondary plant metabolites were not simply plant waste products but served to defend them against insects, herbivores; besides, they also play a number of ecological roles (Iason et al., 2012).

Plentiful secondary metabolites which are synthesized in plants might have the allelophatic potential. They affect the neighbouring species of native flora and other organisms (Inderjit, Duke, 2003). Moreover, many of them usually suppress both seed germination and seedling growth determining initial recruitment and spread of species, and, consequently, impacting plant community restoration in total. However, the phenolic compounds are the most important and common plant allelochemicals (Boudet, 2007; Iason et al., 2012). Moreover, phenolics are known as stimulating the phytotoxicity and inhibiting germination. Phenolics participate in regulation of seed development, germination and plant resistance to various stresses. It is known that phenolics represent the main allelopathic compounds that inhibit different physiological processes of plant, and thereof result in changes of floristic composition within a plant community and dominance of one
plant species over others (Inderjit, 1996). Nonetheless, their content and composition might be different depending on plant species, parts, tissues and cells during ontogenesis and under the influence of various environmental stimuli (Inderjit, Duke, 2003).

Understanding of allelopathic effects, and accepting the role of allelochemicals produced by plant enable a comprehensive analysis of the self-protective and aggressive peculiarities of an invasive plant. For that reason, biochemical studies are required to develop the allelopathy hypothesis and to estimate its relative significance for the explanation of invasive plant spread.

*Solidago canadensis* L. or Canada goldenrod (*Compositae*, syn. *Asteraceae*) originated in North America, recently successfully spread worldwide. This highly aggressive species reduces the communities’ diversity and out-competes all native plants. *S. canadensis* is perennial herb spreading by wind-dispersed seeds forming large colonies that reduce the abundance of native vegetation (Weber, 2000). Though *Solidago* L. genus has ca. 100 herbaceous species in South America, Europe and Asia, all goldenrods are late bloomers, flowers in late summer into the fall, and are common along the edges of moist forests, roadsides and meadows. It was introduced into Europe in 17th century and now has become the most aggressive invader (Weber, 1998) naturalised in Lithuania and has spread in slopes and along international highways.

The main object of this research was to assess a general evidence for allelopathic activity of invasive species *Solidago canadensis* in Lithuania. Additional objectives of the study were to measure the total phenolics content (TPC) in the plant aqueous extracts at different growth stages and evaluate allelochemical potential.

**MATERIALS AND METHOD**

The plants were sampled in spring (May, rosette), summer (June, flowering) and autumn (September, seed maturity) for preparing the aqueous extracts. The biochemical (allelopathic) characteristics of *S. canadensis* aqueous extracts were examined at different plant growth
stages: rosette (39 BBCH; end of May), flowering (65 BBCH; end of June) and milky stage (76 BBCH; end of July). Principal (0-9) and secondary (0-9) growth stages were determined according to the universal BBCH scale description and coded using uniform two-digit code of phenologically similar growth stages of all mono- and dicotyledonous plant species (Meier, 2001). The plants’ samplings were taken when 50% of plants had reached the same developmental stage. Plants leaves, stems, blossoms, seeds and roots were separated and chopped into 0.5 cm length pieces before extraction.

Total phenolics content (TPC) was determined spectrometrically in leachate samples of 0.02, 0.05, 0.1 and 0.2% (w/v) concentrations. Samples were analysed in two replications.

The allelopathic potential of aqueous extracts was expressed in conventional coumarine units (CCU). A universal index of allelochemicals activity of CCU was evaluated for two different acceptors, viz. rapeseed and ryegrass, by a nomogram, which depends on the coumarine allelopathic activity.

Statistical analysis. The confidence intervals of the estimates were based on Student theoretical criterion. Standard deviation (SD) was calculated at p<0.05. Correlation coefficient r between TPC and germination was calculated in order to evaluate their interaction. Significant differences among the means were determined using Tukey’s honest significant difference test. The results of allelopathic effects were statistically evaluated by using the statistical package STATISTICA and R of Stat Soft. The results regarding germination, phenols concentration and CCU are presented as mean ± SD of 4 independent analyses at the p<0.05 significance level.

RESULTS AND DISCUSSION

In order to evaluate phytotoxicity of *S. canadensis*, TPC was perceived in the produced aqueous extracts. It was found that TPC ranged between 0.968 mg ml⁻¹ and 23.591 mg ml⁻¹ and significantly corresponded to the plant growth stage (Fig. 1), plant part (Fig. 2) and extract concentration (r = -0.7) (Fig. 3).
The highest TPC of 23.591 mg ml\(^{-1}\) was observed in extracts produced of plant leaves at flowering stage. Nonetheless, the significant difference of TPC was found only in extracts produced at flowering and seed maturity stages. As phenolic compounds are a remarkable pattern of metabolic plasticity supporting plants adaptation to the changing biotic and abiotic environment (Boudet, 2007), its content was the highest in the main metabolic centres – in the species leaves. Though the highest phenolics content accumulated in leaves, nonetheless its mean content in the shoot decreased during vegetation stages from 7.56 mg ml\(^{-1}\) at rosette to 6.01 mg ml\(^{-1}\) at flowering and 5.67 mg ml\(^{-1}\) at seed maturity stages. Stem lignification and leaves decay at the end of the vegetation might direct to TPC decrease in shoots. Nonetheless, the mean TPC content in roots increased gradually from 9.08 mg ml\(^{-1}\) at rosette to 10.86 mg ml\(^{-1}\) at flowering and 11.06 mg ml\(^{-1}\) at seed maturity stages.

Comparing phytotoxicity of aboveground and underground plant parts of invasive \(S.\ canadensis\), the mean TPC was significantly higher in roots (10.33 mg ml\(^{-1}\)) than in shoots (6.42 mg ml\(^{-1}\)). Roots performed all year, persisting different meteorological conditions, which might stimulate synthesis of phenolics. Nonetheless, Blumenthal (2005) revealed the differences in TPC accumulation in roots and

![Figure 1: TPC distribution at different growth stages of S. canadensis (post hoc Tukey's HSD test)]
shoots depend on species genetically limited biological peculiarities. Relatively high TPC of 10.13 mg ml\(^{-1}\) was found in blossoms. However, the smallest TPC of only 2.30 mg ml\(^{-1}\) was determined in seed.

The most concentrated extracts had significantly highest TPC (Fig. 3). Nonetheless, the TPC differences between roots’ or blossoms’ extracts of different concentration were insignificant.

**Figure 2. TPC distribution in different plant parts of S. canadensis (post hoc Tukey’s HSD test)**

**Figure 3. TPC distribution in different extract concentrations (Conc) of S. canadensis (post hoc Tukey’s HSD test)**
Phytotoxicity of aqueous extracts of invasive *S. canadensis* for different acceptor species was evaluated by CCU (Fig. 4-5). The CCU content is a universal and integrated index of extract phytotoxicity which depends on acceptor species, TPC (r = 0.4 and r = 0.6 for rapeseed and ryegrass respectively) and acceptor germination rate (r = 0.8 and r = -0.7 for rapeseed and ryegrass respectively).

**Figure 4.** CCU range for ryegrass (post hoc Tukey’s HSD test)
As some researchers stated (Moise et al., 2005), the different response of acceptor species to TPC depends on different anatomy and permeability of their seed coats, and thus determines different phenolics through inside seeds and calculated CCU content. A slighter inhibition of rapeseed germination, if opposed to that of ryegrass, may be founded due to different seed coat anatomy and, thus, its permeability.

Figure 5. CCU range for rapeseed (post hoc Tukey’s HSD test). T- CCU content in seed

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**Figure 5. CCU range for rapeseed (post hoc Tukey’s HSD test). T- CCU content in seed**
The germination of acceptor species strongly correlated with TPC (r = -0.5 and r = -0.8) and extract concentration (r = 0.8 for both acceptor species). Nonetheless, the data dispersion was the highest in the highest concentration extract.

CONCLUSION

In general, the content of phenolic compounds was estimated to be different in aqueous extracts of *S. canadensis* due to their dissimilar accumulation in plant parts (root and shoot), growth stage and leachate concentration. As phenolics affect various physiological processes, and thus alter the physiological and growth patterns of plants, the revealed TPC exhibited different allelopathic potential of *S. canadensis* extracts. Thus, the TPC and CCU data suggest that *S. canadensis* might provide the considerably allelopathic influence on the species diversity or local out-competition of the native plants in new habitats. The revealed allelochemical potential of *S. canadensis* should be considered as a partial explanation of high aggressiveness of species in invaded areas. Moreover, the hypothesis that allelopathy increases the invasive potential of *S. canadensis* may contribute a great deal to general models of invasive susceptibility in natural systems. Nonetheless, species evidence for allelopathic effects should not be restricted to TPC and CCU analysis of plant extracts in lab but also grounded on future research in natural ecosystems.

REFERENCES


**Ligita Baležentienė**

**SKIRTINGŲ AKCEPTORIŲ ATSAKAS Į SOLIDAGO CANADENSIS ALELOCHEMINĮ AKTYVUMĄ EX SITU SKIRTINGAILS AUGIMO TARPSNIAIS**

**Santrauka**

Aleloaptija yra naudingas arba žalingas vieno organizmo poveikis kitam, veikiant iškiriamomis biocheminėmis medžiagomis. Augalų bendrijose antriniai metabolitai turi alelocheminį poveikį, slopina sėklų daigumą bei daigų augimą ir yra svarbūs invazinių rūšių pradiniam iškūrimui bei plėtimui.

Buvo nustatytas skirtingas fenolinių junginių kiekis vandeniniuose *S. canadensis* ekstraktuose dėl nevienodo jų kaupimosi augalo dalyse (šaknyse ir ūgliuose) augimo tarpsniais ir ekstraktų koncentracijos. Kadangi fenoliai veikia įvairius fiziologinius procesus, todėl sukelia jų ir augimo kitimą. Nustatytas skirtingas *S. canadensis* ekstraktų alelopatinis potencialas. Tirtų akceptorių rūšių bendro fenolių kieki ir sutartinių kumarino vienetu duomenys patvirtina, kad *S. canadensis* gali alelopatiškai veikti kitų rūšių įvairovę ar lokaliai išstumti vietinius augalus jų buveinėse.

**Reikšminiai žodžiai:** aleloaptija, rykštenė, fenoliai, daigumas, fitotoksiškumas.