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RHUS TYPHINA – FROM ENVIRONMENTAL THREAT TO INDUSTRY DEVELOPMENT OPPORTUNITY

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Abstract
Rhus typhina L. (staghorn sumac) represents a valuable species in terms of its medicinal properties and its wide variety of uses, which deserves more attention in the scientific world. Its fruits contain important amounts of anthocyanins, vitamins, minerals and essential amino acids, while gallic acid and several hydrolyzed tannins are produced by the leaves. Although staghorn sumac has a milky sap that can produce dermatitis and its pollen causes severe allergies, the species has been shown to be useful in treating other disorders such as stomach aches, conjunctivitis and improving the condition of people with diabetes. In the last 10 years the most studies have focused on the ecological impact of this plant and its resistance to different environmental characteristics and less on its bioactivity and chemical composition. As any other invasive species, R. typhina modifies the soil properties and the structure of local plant communities, but is sensitive to light and ozone pollution. In terms of its utility, this species of sumac finds its place in the field of gastronomy, in the production of fuels, cosmetics, pesticides, but also in paper manufacturing.

Keywords: invasive species, plants in industry, staghorn sumac, environmental issues.

1. INTRODUCTION

Invasive plants represent a serious threat to the diversity and conservation of a natural habitat (Wang et al., 2022 c).

Native to Eastern North America (Wang and Zhu, 2017), the invasive ornamental species *Rhus typhina* L. catches the eyes of passers-by in the autumn season when its foliage acquires a strong reddish color (Heine, 2008, Wang et al., 2017).

The sour taste of sumac fruits is attributed to its common name "vinegar tree" (Wang and Zhu, 2017), and their red color led to the name "sumac" (Kossah et al., 2009).

The growth of its leaves for a certain number of days and up to a certain length are genetically determined (Kovalchuk et al., 2022). The stems have a viscous milky sap (Kossah et al., 2009) that can produce dermatitis and other serious skin diseases (Seo et al., 2018).

Staghorn sumac is a clonal shrub or tree (Zhang et al., 2009) with an impressive orange wood with green lines (Kevan, 2009) and an usually exfoliated bark (Kevan, 2009).

Each fruit of this species contains a seed, is covered by multiple trichomes and represents a part of a pyramidal cluster (Kossah et al., 2009).

Even though *R. typhina* was considered a danger to human health (Hulina, 2010), it is also the most traded sumac species (Niemiera, 2009).

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2. METHODOLOGY

In order to have an overview of the topics pursued by researchers in the study of the species *R. typhina*, we used the VOSviewer 1.6.19 program, resulting in associations of keywords repeated at least 5 times in scientific articles indexed in Clarivate-Web of Science and Scopus databases (www.webofscience.com, www.scopus.com). By searching the species name, 141 Web of Science indexed articles and 196 Scopus indexed articles were identified for the selected period (1949-2023). We focused mainly on the Web of science indexed articles, for which we customized the Network visualization, Overlay visualization and Density visualization.

3. RESULTS AND DISCUSSIONS

Analyzing the connection between keywords

Through the investigation on the link between keywords related to *R. typhina*, as illustrated in Figure 1, the presence of three distinct groups was noticed: two of them focused on the chemical composition, and bioactive properties, respectively, and a third group related to the ecology of the species, especially with its allelopathic nature and invasiveness.

We found a close association between the species and bioactive compounds such as gallotannins and gallic acid, but also a link between „leaves" and the antioxidant activity or different biomolecules.

The most frequently associated common name is „staghorn sumac", and there is an important relationship between *R. typhina* and China.

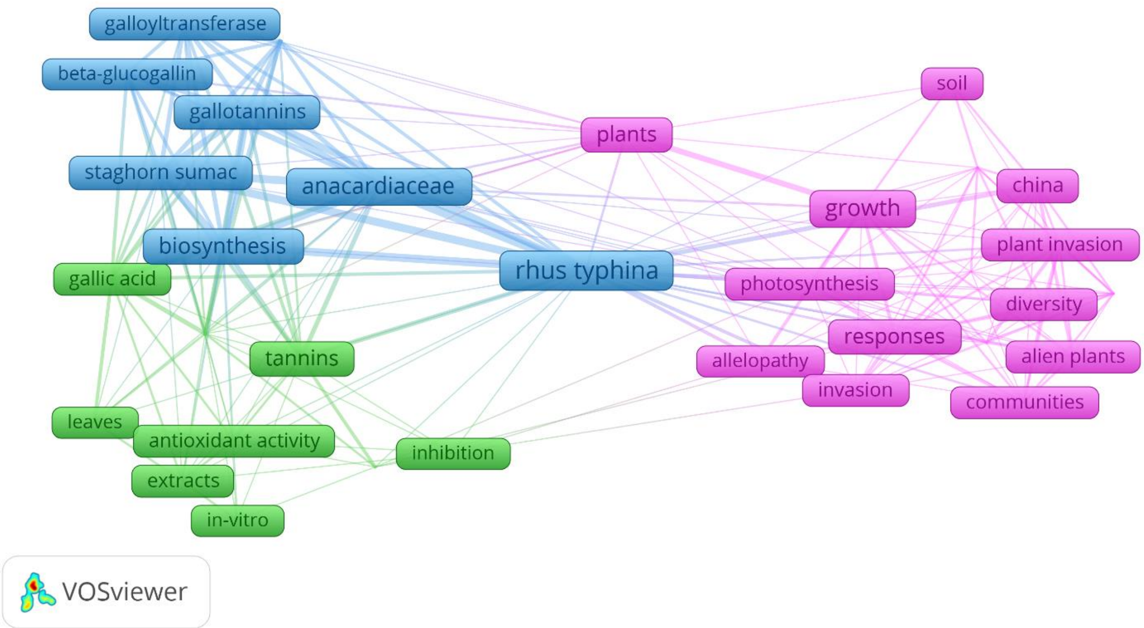

Figure 1. Visualization of links between keywords found in articles on the Clarivate-Web of Science platform by VOSviewer program

Studies until 2010 focused on the chemical composition of staghorn sumac (Figure 2). Since 2015 the influence of this species on the environment and local communities has become of interest, but there were also studies about the antioxidant activity. Based on the number of citations, a higher interest in the biochemical structure of this species than in its effects on the environment could be observed (Figure 3).

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Figure 4 clearly shows the three clusters, with the most representative terms for them: "plants", "growth", "responses" for the pink group, "anacardiaceae" and "biosynthesis" for the blue group and "tannins", " gallic acid" and "extracts" for the green group.

Among the most frequently keywords found in the selected articles are "biosynthesis", "tannins", "anacardiaceae", "growth", "plant invasion" and "diversity" (Figure 5). The words "leaves", "inhibition", "galloyltransferase" and "beta-glucogallin" rarely occurred. The terms „china", „plant invasion", „diversity", „alien plant" are related and could be found in a common article.

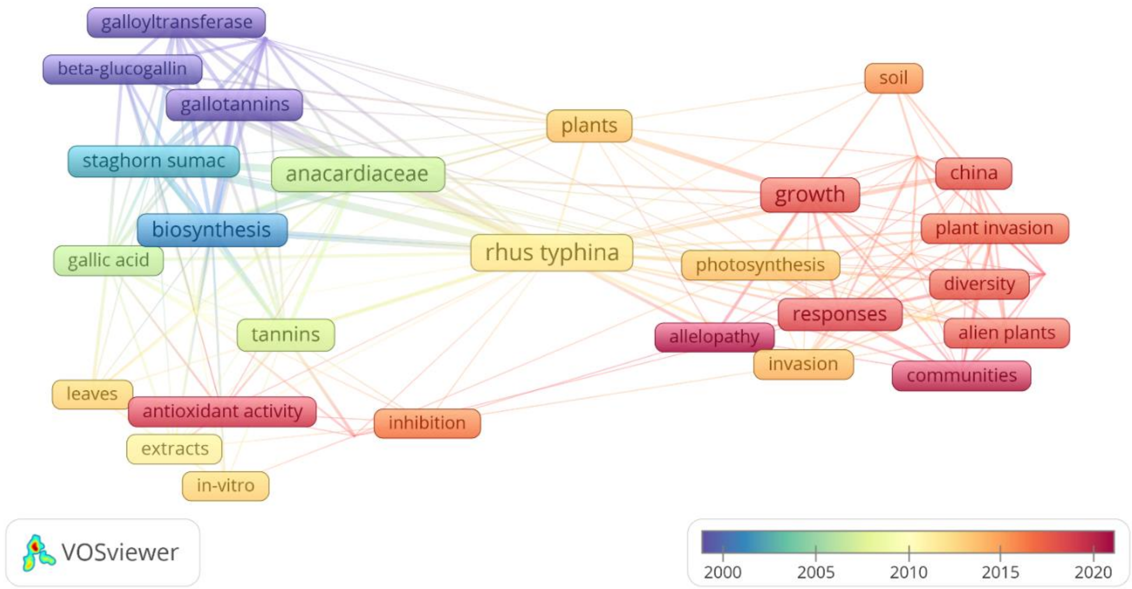

Figure 2. Visualization of studied topics about R. typhina depending on the average year of publication

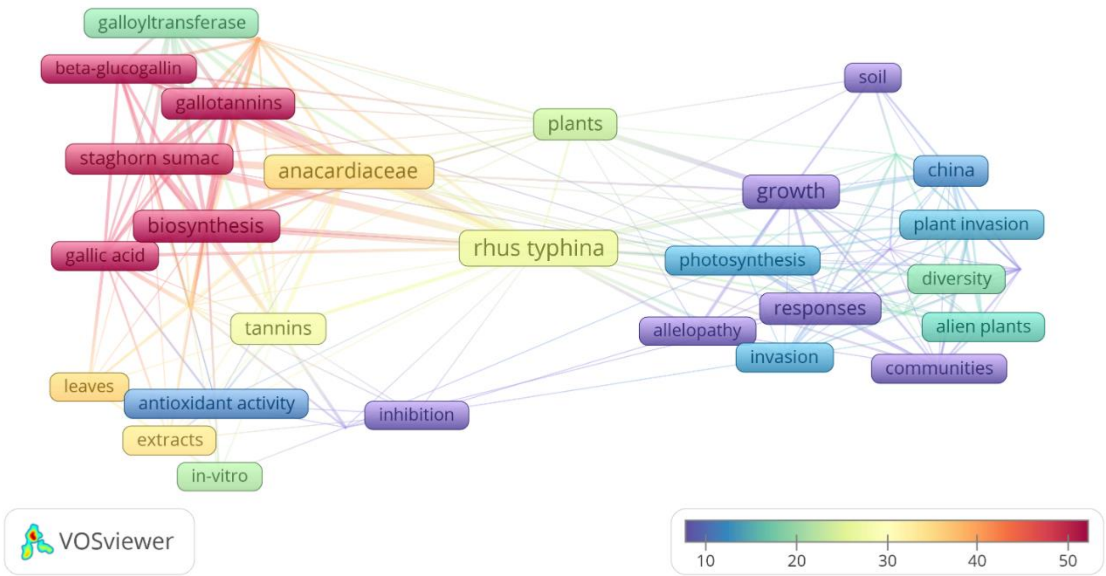

Figure 3. Visualization of studied topics about R. typhina depending on the average number of citations

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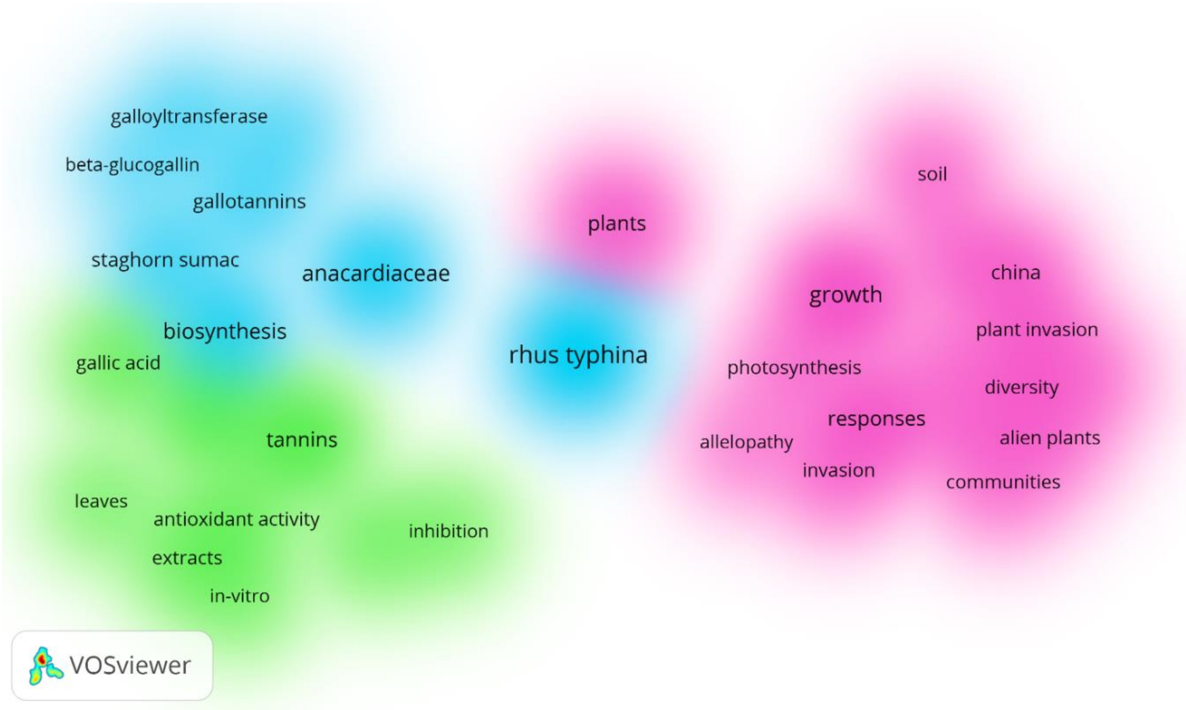

Figure 4. Visualization of the cluster density

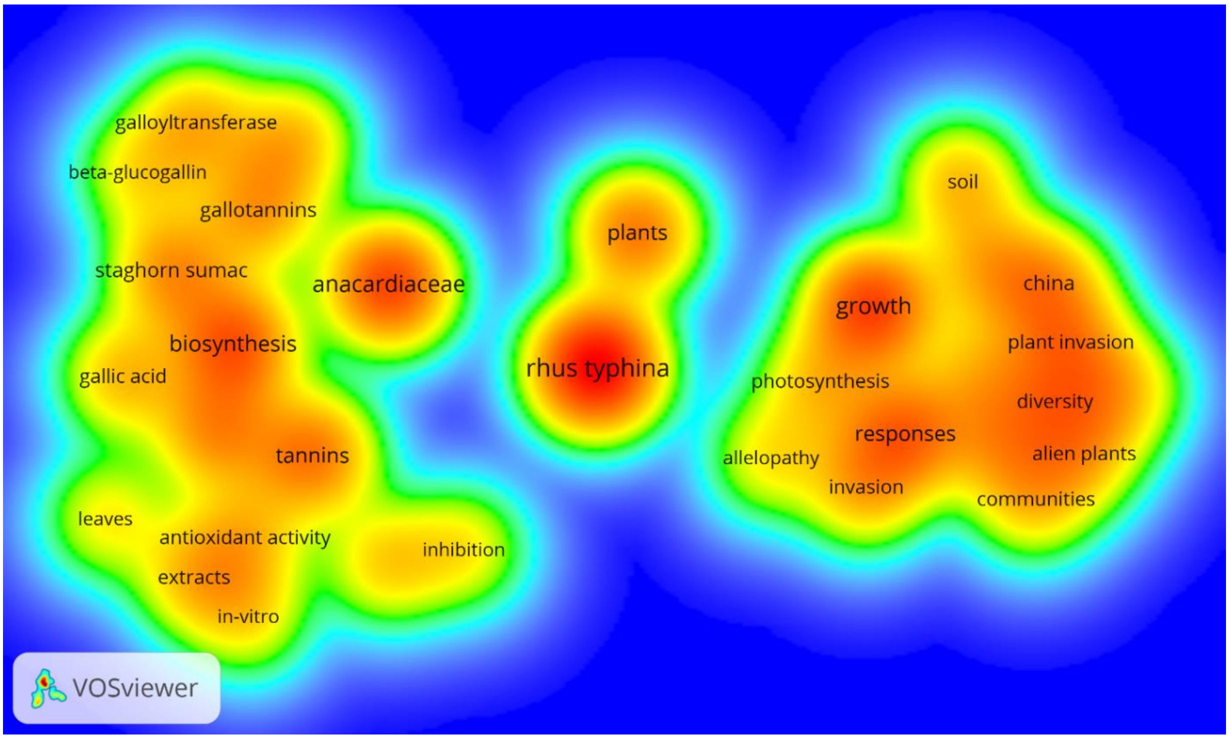

Figure 5. Visualization of the density of items

Figure 6 shows some associations with other important invasive plant species, namely *Ailanthus altissima*, *Robinia pseudoacacia* and *Amorpha fruticosa*.

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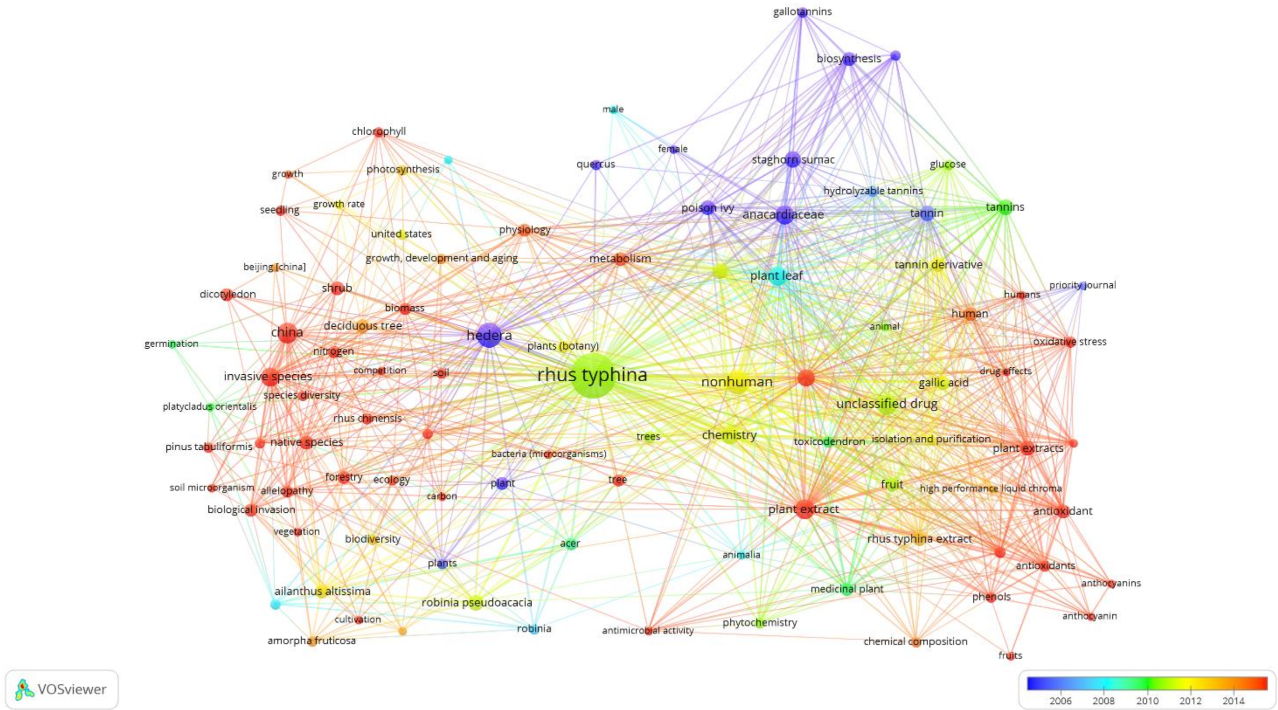

Figure 6. Visualization of topics about R. typhina from Scopus depending on the average year of publication

Aspects regarding the impact of the species *R. typhina* on the environment

Xu et al. (2023) emphasized on the need for in-depth studies on the allelopathy of invasive woody species on native ones. For *R. typhina* such inhibitory effects were reported in different studies.

In mixed culture with the native species *Vitex negundo* var. *heterophylla*, staghorn sumac was able to develop much better than it, becoming the dominant species (Du et al., 2017). In competition with *R. chinensis*, the dominant character was manifested only with the beginning of the autumn period (Bu et al., 2017). Other species on which *R. typhina* showed a competitive advantage were: *Syringa oblata* Lindl. (Guo et al., 2009), *Sapindus mukorossi* Gaertn. (Wang et al., 2016), *Cotinus coggygria* Scop. (Guo et al., 2020) and *Acer truncatum* Bunge (Zhao et al., 2023).

There are also native woody species whose presence can reduce the invasion potential of vinegar tree and increase the resistance of local plant species to its competitiveness (Bin et al., 2019, Yu et al., 2019), as demonstrated in the case of *Pinus densiflora* Siebold and Zucc. (Bin et al., 2019) and *Quercus acutissima* (Yu et al., 2019).

Table 1 shows some examples of species for which sumac is the host, with their complete name and taxonomic classification extracted from NCBI taxonomy database (Schoch et al., 2020).

Phomopsis rhois is an important pathogen of the staghorn sumac that weakens the tree until it dies and the disease produced by it spreads in a relatively short time (Jia et al., 2018). Ascomycetes *Phaeobotryon aplospora* and *Phaeobotryon rhois* are associated with *R. typhina* canker disease (Pan et al., 2019).

R. typhina showed good resistance to different soil moisture conditions, including drought (Du et al., 2017) which has a negative impact on *R. typhina*'s growth capacity, but not as powerful as in native plants (Guo et al., 2020). In arid soils, the release of *R. typhina* allelopathic substances intensifies, so the invasion process of the species is accelerated (Zhong et al., 2023).

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Table 1. Examples of fungus, plant and insect species for which R. typhina serves as host

Species	**Ordo: Family**	**Bibliographic source**
Phytophthora ramorum Werres, De Cock & Man	Peronosporales: Peronosporaceae	Tooley and Browning, 2009
Leiopus linnei Wallin, Nylander & Kvamme	Coleoptera: Cerambycidae	Gutowski et al., 2010
Leiopus nebulosus (L.)	Coleoptera: Cerambycidae	Gutowski et al., 2010
Ceratina dupla Say	Hymenoptera: Apidae	Vickruck et al., 2010
C. calcarata (Robertson)	Hymenoptera: Apidae	Vickruck et al., 2010, Cook et al., 2019
Metcalfa pruinosa Say	Hemiptera: Flatidae	Alina et al., 2013
Melaphis rhois (Fitch)	Hemiptera: Aphididae	Start and Gilbert, 2018
Aplosporella javeedii Jami, Gryzenh., Slippers & M.J.Wingf.	Botryosphaeriales: Botryosphaeriaceae	Zhu et al., 2018, Pan et al., 2019
Aplosporella ginkgonis C.M. Tian, Z. Du & K.D. Hyde	Botryosphaeriales: Aplosporellaceae	Zhu et al., 2018
Phaeobotryon aplospora M. Pan & X.L. Fan	Botryosphaeriales: Botryosphaeriaceae	Pan et al., 2019
Phaeobotryon rhoinum X.L. Fan	Botryosphaeriales: Botryosphaeriaceae	Pan et al., 2019
P. rhois C.M. Tian, X.L. Fan & K.D. Hyde	Botryosphaeriales: Botryosphaeriaceae	Pan et al., 2019
Cuscuta japonica Choisy	Solanales:Convolvulaceae	Qu & Fan, 2020
Cytospora melnikii Norphanph., Bulgakov, T.C. Wen & K.D. Hyde	Diaporthales: Valsaceae	Zhu et al., 2020 (a)
Cytospora chrysosperma (Pers.) Fr.	Diaporthales: Valsaceae	Wang et al., 2022 (b)

The good resistance of staghorn sumac to dehydration is maintained even during the summer (Akhmatov, 2017) and as autumn advances, transpiration and photosynthesis decline, while the species uses water resources more efficiently (Guo et al., 2010). The triacylglycerol profile of *R. typhina* seed oil can be slightly altered by temperature and geographic area (Zhang et al., 2022).
The two-month-old staghorn sumac seedlings showed a high survival rate under low sunlight conditions (Zhang et al., 2009). To gain access to an ample amount of light, *R. typhina* invests more than other species in height growth and its leaf biomass (Tan et al., 2018). It successfully adapts to sudden changes in light intensity (Qi et al., 2022). However, the species is sensitive to light pollution that can delay the establishment of the autumnal phenotype (Škvareninová et al., 2017), but also to ozone pollution (Seiler et al., 2019) and accumulates large amounts of phosphorus (Shi et al., 2012). As confirmed by the experiment by Dzhygan et al. (2018), pollution caused by vehicle emissions led to the decrease of chlorophyll in staghorn sumac leaves. Even so, Nuermaimaiti et al. (2022) noticed a good absorption capacity for air medium-sized particles. Apparently, this species has a high potential to reduce air pollution caused by heavy metals such as zinc, cromium, copper, lead or manganese, which are accumulated especially in its leaves and bark (Liu et al., 2022).
Moreover, substrate heterogeneity gives *R typhina* a strong competitive advantage over native species (Hu et al., 2022).

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In a study regarding the forests of Dobrogea, preference for 101-150 m altitude was found for the *R. typhina* , growing on soils such as lithic rendzina, regosol, chernoziom, etc. (Timiş-Gânsac & Dincă, 2020). The cultivation limits, according to Cui & Huang, (2009) can be expanded with the accentuation of global warming, as vinegar tree is a thermophilic species (Cui & Huang, 2009).
Higher leaf nitrogen and chlorophyll content and greater leaf area variability could be associated with a higher success rate of the species (Wei et al., 2020). The gradual, unnatural accumulation of nitrogen in the soil favors the spread of the invasive species, improving its production rate and photosynthetic capacity and stimulating its growth (Wang et al., 2022 a). Wang et al., 2022 c sustained that by its installation in the environment, *R. typhina* changes the soil features, alkalinizing it and increasing its nitrogen content, so that future shoots can spread easily (Hou et al., 2015, Wang et al., 2022 c). Li et al., 2023, on the contrary, found a decrease in the nitrogen amount and no influence of the microbiota to the subsequent invasion of the area by different herbaceous plants. Hou et al., (2015) observed that in the soil of a *R. typhina* forest the total nitrogen and nitrate nitrogen increased, while ammonium nitrogen decreased, but Wang et al. (2022 c) noticed the opposite in pastures with different rates of invasion. The dominant form of nitrogen found in soil can influence the activity of the peroxidase, the strongest spread of the species being found when ammonium is added to the medium (Zhong et al., 2022). The presence of staghorn sumac increased the level of potassium, but decreased the level of available phosphorus (Wei et al., 2020) and could change the structure of nitrogen-fixing bacterial communities (Wu et al., 2019) or increase of Actinobacteria content higher than normal (Zhu et al., 2020).
Even though in the Zhu et al. (2020) study, *R. typhina* leaf extract showed insignificant soil enzyme inhibition effect, an older study of Hou et al. (2015) described the increase of urease and catalase activity and reduction of phosphatase action in a staghorn sumac forest.
Planting *R. typhina* in iron tailings sites increased soil quality by increasing its clay content (Wang et al., 2020). Its planting in coastal saline-alkaline lands coud improve soil quality by lowering its salinity and increasing its fertility (Zhang et al., 2018, Liu, 2019 b), but with a lower effect than that of *R. pseudoacacia* (Liu, 2019 b).
In former mining areas, vinegar tree planting led to an increased soil fertility and moisture, this plant proving to be suitable for rehabilitation of these lands (Yan et al., 2020 b). The species can be found in these areas, sporadically and with small numbers of individuals, even if it is not planted (Gräser & Ries, 2020). In the mining areas of a quarry (Ma et al., 2022) or on surface mines (Branduzzi et al., 2022), its presence seemed to prevent the restoration of natural grass plant communities, so its use in the ecological rehabilitation of these areas is not indicated (Yan et al., 2020 a, Ma et al., 2022).
Staghorn sumac is a suitable species for afforestation of areas that are more difficult to handle such as the limestone low mountains and hills (Chen & Wan, 2009) and it is among the plant species that have managed to adapt to the harsh conditions at the apex of Mount Baldy (Keweenaw Peninsula) (Ney & Nichols, 2009).
Unfortunately, it penetrated into protected areas such as site ROSCI0383 Târnava Mare River between Odorheiu Secuiesc and Vânători (Danci & Oancea, 2019) and Kampinos National Park (Bomanowska et al., 2019)
About the impact of staghorn sumac on pollinators, the reproducibility and colony weight of *Apis mellifera* L. from a non-agricultural area where the collected pollen came mostly from *R. typhina* were significantly lower, according to Alburaki et al. (2017), than those of colonies in agricultural areas.

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Regarding the control of this species, *Amorpha fruticosa* and *Robinia pseudoacacia* root leachates showed a potential to inhibit the germination and development of *R. typhna* seedlings (Wei et al., 2017). Staghorn sumac shows high resistance to the action of pests (Li et al., 2009) having a high capacity for regeneration, including above-ground plant material, mechanical control cannot help stop the invasion of this species (Monty et al., 2015).

Traditional and modern uses of the species

R. typhina has been seen in folk medicine as a blood purifier, antiseptic or tonic (Kossah et al., 2009). Regarding the bioactive compounds, including fustin and quercetin, the species strain could have a strong antioxidant effect, being suitable for different applications (Liu et al., 2019 a). Table 2 shows some examples of biomolecules detected in the composition of *R. typhina*.

Olchowik-Grabarek et al. (2017) observed that sumac leaves contain important hydrolyzable tannins which are efficient in reducing oxidative stress and inflammatory processes. The same compound, according to Sekowski et al. (2017) may reduce the risk of developing Parkinson's disease by slowing the formation of Lewy bodies from α-synuclein aggregation. Hydrolyzable tannins in vinegar leaves protected red blood cells from oxidative stress caused by hydroquinone and bisphenol A, inhibiting hemolysis and increasing the stiffness of erythrocyte membranes (Olchowik-Grabarek et al., 2018).

Wang et al. (2019) observed that the ethyl acetate fraction of an extract from *R. typhina* fruits has antiproliferative effect on HT-29 cells, being useful in drug production.

Methanolic extracts from the bark, leaves and flowers of the vinegar showed a strong inhibitory effect on the proteases thrombin, trypsin and urokinase (Jedinak et al., 2010). *Rhus typhina* has shown promising results in treating generalized periodontitis (Blavatska et al., 2018).

The species inhibits the development of bacteria such as *Escherichia coli* (Borchardt et al., 2009, Vandal et al., 2015, Zazharskyi et al., 2020, Cloutier & MacTaylo, 2022), *Pseudomonas aeruginosa* (Borchardt et al., 2009, Cloutier & MacTaylo, 2022), *Staphylococcus aureus* (Borchardt et al., 2009, Zazharskyi et al., 2020, Cloutier & MacTaylo, 2022), *Enterococcus faecalis*, *Salmonella typhimurium*, *Rhodococcus equi*, *Proteus vulgaris*, *Listeria ivanovi*, *Corynebacterium xerosis* (Zazharskyi et al., 2020) and *Vibrio parahaemolyticus* (Cloutier & MacTaylo, 2022). *Candida albicans* was also afected by the extracts of *R. typhina* (Borchardt et al., 2009, Vandal et al., 2015).

Gallic acid, caffeic acid and ethyl gallate are compounds found in staghorn sumac, which have shown important bactericidal effects on *S. aureus* and *M. phlei* (Vandal et al., 2015). *Helicobacter pylori* is sensitive to the ethanolic extract from the fruit of *R. typhina* (Kossah et al., 2011), but also the yeast *Pichia pastoris* (Kossah et al., 2011). The tannins from sumac leaves have also a bactericidal effect on the species *B. cereus* (Olchowik-Grabarek et al., 2014). Its aqueous and ethanolic extracts inhibit the growth of the pathogenic bacterium *Erwinia amylovora* (Krupiński & Sobiczewski, 2013). The ethanolic extract of *R. typhina* leaves showed strong inhibitory effect on the growth of the pathogenic microfungi *Fusarium solani*, *Pythium* spp., *Phytophthora sojae* and *Rhizoctonia solani* (Lis, 2009).

Species of plants, arachnids and insects on which *R. typhina* had a pesticidal effect include: *Tetranychus urticae* Koch and *Tetranychus viennensis* Zacher (Zhongxin et al., 2010), *Lolium perenne* L. and *Poa pratensis* L. (Zuo et al., 2021), *Myzus persicae* (Sulz.), *Metopolophium dirhodum* (Walk.) and *Aphis fabae* Scop. (Klingauf et al., 1988), *Ailanthus altissima* and *Pinus tabulaeformis* (Sun et al., 2010), *Lepidium sativum* L. and *Raphanus raphanistrum* subsp. *sativus* (L.) Domin (Ivanko et al., 2022), *Trifolium pratense* L. and *Agrostemma githago* L. (Zhu et al., 2020 b).

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Table 2. Bioactive compounds found in staghorn sumac

Organ	Compound name	Bibliographic source
Leaf	3,6-bis-O-di-O-galloyl-1,2,4-tri-O-galloyl-β-D-glucose	Olchowik-Grabarek et al., 2017
	rutin	Olchowik-Grabarek et al., 2017
	1,2,3,4,6-penta-O-galloyl-β-D-glucose	Olchowik-Grabarek et al., 2017
	4,6-di-*tert*-butyl-2-methylphenol	Li et al., 2009
	butylated hydroxytoluene	Li et al., 2009
	α-farnesene	Li et al., 2009
	undecaprenol	Vanderwekken & Martin-Vissche, 2018
	luteolin	Wang et al., 2015
	luteolin-7-O-glucuronide	Wang et al., 2015
	2,3-di-O-galloyl-β-D-glucose	Olchowik et al., 2012
	kaempferol	Olchowik et al., 2012
	caryophyllene	Bestmann et al., 1988
	byzanethanoside B	Liu et al., 2019 b
	blumenol C glucoside	Liu et al., 2019 b
	(6R,9S)-3-oxo-α-ionol-β-D-glucopyranoside	Liu et al., 2019 b
	rutin	Bohinc et al., 2020
	naringin	Bohinc et al., 2020
Stem	gallic acid	Liu et al., 2019a
	1-O-galoyl-β-D-glucose	Liu et al., 2019a
	methyl gallate	Liu et al., 2019a
Fruit	ellagic acid	Lai et al., 2014, Wang et al., 2023
	caffeic acid	Wang et al., 2023
	quercetin	Lai et al., 2014, Wang et al., 2023
	catechyin hydrate	Bohinc et al., 2020
	citric acid	Popov, 2018
	tartaric acid	Popov, 2018
	kaempferol	Qiu et al., 2016
	gallic acid	Qiu et al., 2016
	friedelin	Qiu et al., 2016
	palmitic acid	Demchik et al., 2015
	linoleic acid	Demchik et al., 2015
	7-O-methyl-delphinidin-3-O-(2'''galloyl)-β-D-galactopyranoside-4-vinyl-catechol-3''-O-β-D-glucopyranoside	Lai et al., 2014
	7-*O*-methyl-cyanidin-3-*O*-(2″galloyl)-β-d-galactopyranoside	Kirby et al., 2013

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Xu et al. (2010) noticed that leaves decomposed for 1–5 days inhibited the growth of *Brassica chinensis*. Wang et al. (2017) found that both red and green leaves of vinegar tree show herbicidal effects on the *Lactuca sativa* species, the former having a more pronounced action. Aqueous extracts of sumac leaves, roots and fruit showed antigerminative potential against the species *Cosmos bipinnata* Cav., the weakest potentiation being found in the fruit extract and the toxicity increasing with the concentration (Qu et al., 2017). Aqueous extract of staghorn sumac fruits delayed the germination of wheat caryopses and significantly decreased their germination rate (Yan et al., 2009, Sun et al., 2010). *R. typhina* tannins showed strong antihelmintic effects on *Caenorhabditis elegans* (Katiki et al., 2013).

The aqueous extract of staghorn sumac fruit proved to be a good natural food preservative; by adding less than 4% of it to the bread composition the appearance of mold could be slowed, insignificantly changing the volume, texture and taste (Wang & Zhu, 2018).

A bright red natural dye was obtained from the *R. typhina* fruit by ethanol extraction and it was tested on *Ailanthus altissima* wood (Horvat et al., 2020).

By dyeing untreated or pretreated pieces of cotton with soy milk, Petrovčič (2020) found out that more intense and darker red and yellow shades for these could be obtained by applying aqueous sumac extracts than alcoholic ones.

As a pH indicator, the dye in the vinegar fruit can change color from red in acidic pH to yellow in basic pH (Horvat & Iskra, 2020).

Aqueous extract of vinegar leaves gave good results in obtaining cotton fabrics with silver nanoparticles that show a pleasant color, UV protection and strong antibacterial effect, but further studies are needed on the retention of these properties after washing (Savio, 2020) .

With its high hemicellulose content and low ash content, the plant is suitable for the production of good quality paper (Kapun et al., 2022).

The plant contains compounds that give it the quality of a promising raw material for obtaining cosmetic products for scalp and hair health care (Wang and Zhu, 2017).

From the seeds and fruit of this species could be obtained a biodiesel that meets the standards of a good quality fuel (Zhang et al., 2018, Khan et al., 2019).

Vinegar could represent an important fodder species for ruminants due to its rich fiber and protein content and the ability to reduce the amount of methane produced by them through digestion (Jayanegara, 2009 b), an important role in this sense having hydrolyzable tannins (Jayanegara, 2009 a). Staghorn sumac is also used in various places to stabilize sandy soils (Zhang et al., 2009)

4. CONCLUSIONS

Rhus typhina is an invasive woody species that changes the nitrogen content of soil and other chemical elements as well, influences the microbial composition and enzymatic processes of the substrate

Although it is sensitive to different types of pollution, climate change favors its spread and increases its competitiveness in relation to other native or even invasive trees and shrubs.

Although it is suitable for rehabilitating heavily degraded soils from mining or afforestation of poor or highly alkaline soils, its allelopathic effects on native grass species is not recommended.

The chemical composition of *R. typhina* consists of hydrolyzable tannins, flavonoids, anthocyanins and different volatile compounds, making the species a potential valuable source for the pharmaceutical industry, based on confirmed antimicrobial and antioxidant properties, and for industrial application based on the potential to be used as natural dyes and biopesticides. Future studies could focus on the industrial potential of vinegar flowers. There is still a necessity to

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accumulate information on how the application of staghorn sumac extracts affects local non-target species.

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