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Original Paper

Allelopathic Effect of *Ailanthus altissima* Extracts on Tomato Seeds

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The tree-of-heaven plant, due to the content of secondary metabolites with a variety of unique properties, is widely studied as a potential raw material for obtaining remedies for organic farming. Our work aimed to study the allelopathic effect of *Ailanthus altissima* extracts on tomato (*Lycopersicon esculentum*) seeds. Dry plant materials of ailanthus (leaves and seeds) were extracted with distilled water and applied to tomato seeds at a concentration of 15, 10, and 5 mg.ml^{-1} of dry residue to investigate their impact on the energy of germination, total germination, length of radicles and hypocotyls. The result revealed that the ailanthus extracts from leaves, collected in June, and from seeds, collected from July, had a significant inhibitory effect on all studied parameters. The total germination rate of seeds was suppressed on average by 56.2–69.0% compared to the control, and by 44.2–57.0% compared to the chemical standard. The length of the tomato radicles decreased by 1.4–18.6 times compared to the control. The most significant decrease was observed in germination energy and hypocotyl length. All three ailanthus extracts tested in the concentration of 15 mg.ml^{-1} significantly inhibited germination energy and hypocotyl growth of tomato seeds. It was concluded that the leaves and immature seeds of *Ailanthus altissima* contain potential allelopathic substances that affect the energy of germination, and total germination rate, and inhibit the hypocotyl and radicle length of tomatoes. Therefore, aqueous extracts of ailanthus should be used to protect tomato fields from weeds only in the post-emergence period.

Keywords: *Ailanthus altissima*, plant extracts, allelopathic effect, tomato seed, germination

1 Introduction

Ailanthus altissima (Mill.) Swingle (tree-of-heaven), family Simaroubaceae DC. (*A. altissima*) is a perennial deciduous tree or shrub that reaches a height of 15–30 m. The plant is believed to be native to East China and North Vietnam, where *A. altissima* is a major component of broadleaf forests (Kowarik and Säumel, 2007). However, according to other sources, the natural range is more widespread and covers Northeast and Central China, as well as East and Southeast Asia – Taiwan, North Vietnam, and North Korea (Hoshovsky, 1988; Huang and Editorial Committee of the Flora of Taiwan, 2003; Yonebayashi et al., 2016). Tree-of-heaven was introduced to Europe by the French missionary Pierre d'Incarville in the 1740s, and in 1784–1785 by William Hamilton the plant was brought to the United States, Philadelphia (Kowarik and Saumel, 2007; Boer, 2013; Kasson et al., 2013). It is currently distributed in tropical and subtropical eastern Asia, Europe, North and South America, Africa, Australia, New Zealand (Weber, 2003; Weber and Gut, 2004; Fotiadis et al., 2011; Galasso et al., 2018).

Due to its bioecological features, namely unpretentiousness to soil and climatic conditions – adaptability to any type of soil – acidic, neutral, alkaline, resistance to drought, frost, heat, hydrogen fluoride, sulphur dioxide, poor, dry or wet soils, pollution, heavily polluted soils, and industrial pollution, resistance to pests and diseases, the tree-of-heaven spreads at an incredible rate, easily adapts to new habitats and produces abundant, fast-growing shoots. Renewal is both seed and root offspring. Seed production per mature *A. altissima* plant can reach one million per year or more (Rebbeck and Jolliff, 2018). Reproduction from seeds in the total number of young shoots can reach more than 40%. While seed propagation is not uncommon, the fastest regeneration method for ailanthus is through roots, root crown, and bole (Sladonja et al., 2015; Boer, 2013; Rebbeck and Jolliff, 2018). Even young ailanthus

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seedlings can produce horizontal roots from which new shoots appear.

Thus, the plant is essentially a weed, multiplies quite easily, and gives plentiful annual growth. At the same time, the composition of various parts of the plant includes secondary metabolites that have biological activity against other weed plant species, as well as concerning harmful species of insects and mites (Kozuharova et al., 2022). Because of this unique combination of properties, it is advantageous to use the plant as a raw material for the production of different remedies for organic farming. Therefore, research is being carried out all over the world on the study of herbicidal, pesticidal, antimicrobial, antioxidant, and other beneficial properties of extracts and essential oil from ailanthus (Tsao et al., 2002; De Feo, 2009; Pedersini et al., 2011; Albouchi et al., 2013; Sladonja et al., 2014; Poljuha et al., 2017; Ivanova and Elisovetcaia, 2018; Demasi et al., 2019; Caser et al., 2020; Tanasković et al., 2021).

Simultaneously with the study of herbicidal properties, extracts from *A. altissima* revealed the presence of allelopathic activity (Constan-Nava, 2015; Ullah et al., 2020). Based on the foregoing, before recommending extracts or remedies based on the secondary metabolites of ailanthus, it is necessary to comprehensively study their effect on cultivated plants. Therefore, our work aimed to study the allelopathic effect of *Ailanthus altissima* (Mill.) Swingle extracts from leaves and seeds on *Lycopersicon esculentum* Mill. (*L. esculentum*) seeds.

2 Material and methods

The laboratory experiments were carried out during 2022–2023, in the Slovak University of Agriculture (SAU) in Nitra, Institute of Plant and Environmental Sciences, Nitra, Slovak Republic.

2.1 Plant materials

Ailanthus leaves and seeds were harvested in the central zone of the Republic of Moldova from adult fruit-bearing trees. The leaves were collected in May before flowering and in June during flowering. The seeds were harvested at the end of July 2022. All plant materials were dried at room temperature away from sunlight, and then crushed using the laboratory mill, powdered to uniform-size of particles passing through a sieve with apertures 1.0 mm in diameter and suppose to extraction.

Allelopathic effect of *A. altissima* extracts was studied using tomato seeds *Lycopersicon esculentum* (variety Prestige) which were obtained from the Laboratory of Vegetal Biotechnologies, Institute of Genetics, Physiology and Plant Protection (IGPPP), Chisinau, Republic of Moldova. Seeds were selected in such a way that the initial germination was within 70–80%. This range allowed us to more accurately determine whether extracts from *Ailanthus altissima* have an allelopathic effect, or maybe they stimulate the germination of tomato seeds.

2.2 Standard

Glifostar 480 SL, a systemic non-selective herbicide with a very broad spectrum of action, in which the isopropylamine salt of glyphosate serves as an active component, was used as a chemical standard. Glifostar 480 SL is used on over 150 crops (including tomatoes) before sowing or before emergence against vegetative weeds. It is effective against more than 100 species of annual and perennial monocotyledonous and dicotyledonous weeds and leads to the complete death of both the ground part and the roots of plants. Glyphosate is currently approved in the EU until December,15, 2023, and also registered in the Republic of Moldova (The European Commission's

Table 1 Variants for testing *Ailanthus altissima* aqueous extracts for allelopathy activity

Nr.	Variants	Abbreviations	Concentration (mg.ml^{-1})
1	Control (distilled water)	control	–
2	Standard (Glifostar)	standard	10
3	Aqueous extracts from leaves collected in May 2022 (AM)	AM 15	15
4		AM 10	10
5		AM 5	5
6	Aqueous extracts from leaves collected in June 2022 (AJn)	AJn 15	15
7		AJn 10	10
8		AJn 5	5
9	Aqueous extracts from seeds (AJl)	AJl 15	15
10		AJl 10	10
11		AJl 5	5

food safety, 2023; The state register..., 2022). Glyfostar was chosen specifically to compare the negative (herbicidal) effect on tomato seeds of this chemical preparation and plant extracts.

2.3 Extraction

Ailanthus leaves and seeds were harvested in the central zone of the Republic of Moldova from adult fruit-bearing trees. The leaves were collected in May before flowering and in June during flowering. The seeds were harvested at the end of July 2022. All plant materials were dried at room temperature away from sunlight, and then crushed using the laboratory mill, powdered to uniform-size of particles passing through a sieve with apertures 1.0 mm in diameter.

The dry, crushed, and powdered of *A. altissima* plant raw material was extracted with distilled water in the ratio dry plant materials: solvent – 1 : 10. The mixture was shaken for 4 hours on a laboratory shaker, and then infused for 48 hours, followed by filtration through a pleated filter paper. The obtained filtrates were brought to a boil, cooled, and then used. The dry residue in the extract was determined on the Moisture analyzer MAX series RADWAG 26 – 600 Radom and serial dilutions (based on distilled water) were prepared from all three initial extracts from leaves and seeds with the following concentrations: 15, 10, and 5 mg of dry residue per milliliter (Table 1).

2.4 The allelopathic effect

The allelopathic effect of aqueous extracts from *A. altissima* was studied using tomato (*Lycopersicon esculentum* Mill.) seeds of the Prestige variety with a germination rate above 70%. Seeds with low germination were used, since, according to some literature data, ailanthus extracts can stimulate seed growth (Tsao et al., 2002). Seeds were treated by immersion for 30 minutes in 0.5% solutions of potassium permanganate. Then the seeds were washed three times with distilled water. One layer of filter paper was placed in Petri dishes with a diameter of 9 cm, 1 ml of the solution was applied to the filter paper. After distributing the solution over filter paper, *L. esculentum* seeds were placed in Petri dishes, covered with one layer of filter paper, and 3.0 ml of distilled water was added. A solution of Glifostar at the recommended concentration of 10 ml per 1 l of water was used as a standard. As a control, the treatment of filter paper with distilled water was used in the same way as described above. Each variant consisted of four replicates, 100 tomato seeds per replicate. All tested variants are presented in Table 1.

The seeds were germinated in Petri dishes between moistened filter paper disks in a thermostat at the temperature of 25 °C in the dark (ISTA, 2023). The germination energy, total germination rate, the length of roots, and hypocotyls were determined. Germination energy was taken into account on the 7th day, and the total germination rate was recorded on the 14th day (Bralewski et al., 2004). Germination energy (*GE*) was calculated according to the following equation:

$$GE = n_7 / n_i \times 100$$

where: *GE* – germination energy (%); n_7 – number of germinated seeds for 7th day; n_i – number of seeds used

Germination rate (*GR*) was calculated according to the following equation:

$$GR = n_{14} / n_i \times 100$$

where: *GE* – germination rate (%); n_{14} – number of germinated seeds for 7th day; n_i – number of seeds used

The allelopathic effect of aqueous extracts of *A. altissima* at 5, 10, and 15 mg.ml^{-1} on tomato seeds were determined according to standard methods concerning control and standard (Novak, 2019). Allelopathic efficacy was assessed by the inhibition of seed germination in comparison with the control, as well as by the effect on the length of radicles and hypocotyls of tomato seeds.

2.5 Statistical analysis

Values of the germination energy and total germination were presented as the mean of four replicates. The length of the radicles and hypocotyls was calculated for each variant for all germinated seeds. The obtained data were analyzed by Duncan's Multiple Range Tests. Significant differences among the mean values were compared by Tukey's HSD test (HSD – Honestly Significant Difference) at level α (0.01, 0.05, 0.001) with Statgraphics Plus 5.0 and Statistica 10.1.

3 Results and discussion

3.1 Allelopathy effect of aqueous extracts on seed germination

As a result of testing three aqueous extracts from the leaves and seeds of *Ailanthus altissima* at a concentration of 5, 10, and 15 mg.ml^{-1} of dry residue, it was found that in the control and standard, the germination energy of *Lycopersicon esculentum* seeds is significantly higher than in the variants with treatment with ailanthus extracts (Fig. 1).

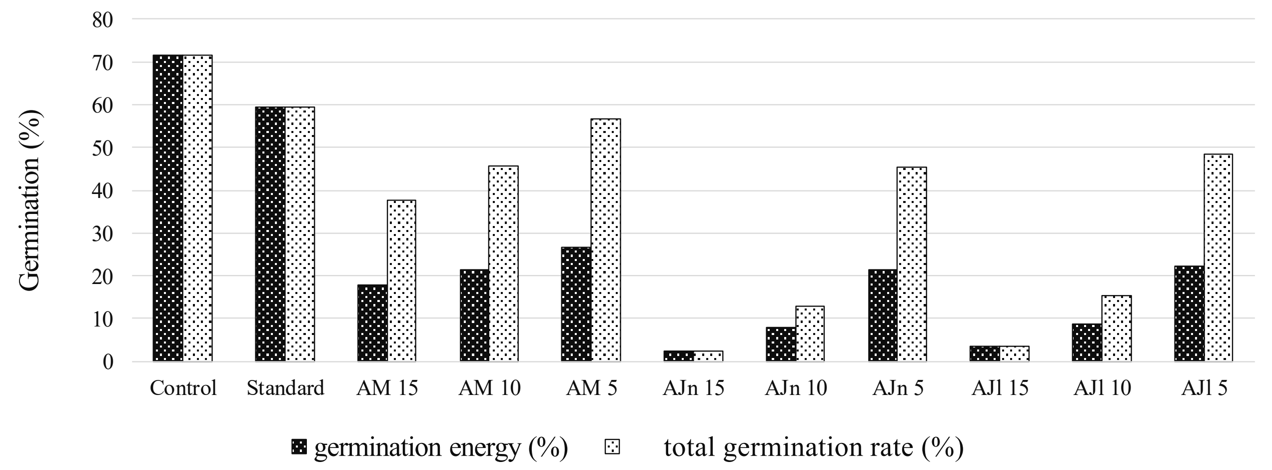

Figure 1 Allelopathic effect of aqueous extracts from *Ailanthus altissima* on germination energy and total germination rate of the *Lycopersicon esculentum* seeds

The lowest germination energy of tomato seeds was found in variants AJn15 and AJl15. The germination energy of tomato seed increased with a decrease in the concentration of *A. altissima* extracts. The enhancement of the allelopathic action of the tested extracts can be represented in the following sequence: AJn15 > AJl15 > AJn10 > AJl10 > AM15 > AM10 > AJn5 > AJl5 > AM5 > Standard > Control. Thus, in all variants with the treatment of seeds of *L. esculentum* with extracts of *A. altissima*, we observe suppression of germination energy of tomato seeds, i.e. the aqueous extracts of ailanthus exhibited allelopathic effect.

It was found that aqueous extracts from leaves of *Ailanthus altissima*, collected in May 2022 (AM), showed the least allelopathic effect (Figure 1, Table 2). However, it should be noted that this extract at all three tested concentrations still significantly (p ≤0.05) suppressed seed germination – by 14.7–33.7% in comparison with the control (Table 2). Also, the AM extract at concentrations of 10 and 15 mg.ml^{-1} significantly affected the germination of tomato seeds in comparison with the chemical standard Glyphosate, the germination decreased by 13.7 and 21.7%, respectively. At the lowest concentration (5 mg. ml^{-1}) of AM extract, the germination of tomato seeds was at the level of the standard. Statistical analysis of the data showed that aqueous extracts from leaves collected in June (AJn) at all tested concentrations and from seeds (AJl) at 15 and 10 mg.ml^{-1} reduced significantly (p ≤0.001) the germination of tomato seeds in comparison with both control and standard. AJl5 extract showed an allelopathic effect at the level of the standard, while suppressing the germination of tomato seeds more than the standard by 8.3% (Table 2). According to the degree of total germination suppression of seeds, the tested extracts were distributed in the same sequence as to the allelopathic effect on seed germination energy: AJn15 > AJl15 > AJn10 > AJl10 > AM15 > AM10 > AJn5 > AJl5 > AM5 (Fig. 1, Table 2). No stimulating effect of water extracts of ailanthus from various parts of the plant on the germination of tomato seeds was found.

It was found that the suppression of tomato seed germination directly depends on the concentration of aqueous extracts from ailanthus (Figure 1, Table 2). With an increase in the concentration of active substances, the rate of germinated seeds decreased. Extracts from ailanthus leaves collected in June (AJn), as well as extracts from ailanthus seeds collected in July (AJl) at a concentration of 15 and 10 mg.ml^{-1}, had the highest allelopathic effect (Figrue 1, Table 2). Total germination of tomato seeds in comparison with the control under the influence of these extracts decreased by 68.0–69.0% and 56.3–58.3% at a concentration of 15 and 10 mg. ml^{-1}, respectively. Our data are partly consistent with those previously obtained by Ullah et al. (2020), who tested aqueous extracts based on fresh and dried plant material from the leaves of *Ailanthus altissima*, collected in February (Pakistan), against the seeds of *Triticum aestivum* L. (Ullah et al., 2020). It was found that the extract of both fresh and dried leaves of *A. altissima* has an inhibitory effect on the germination, the length of feathers, and roots of *T. aestivum*. The difference between the reported and our results consists of the dependences of the inhibitory effect on the concentration of extracts. A direct relationship between the concentration of active components in the ailanthus extracts and the germination rate of seeds was shown in our experiment, while in the experiment described by Ullah et al. (2020), the clear dependence of seed germination on the concentration of extract from dried ailanthus leaves was not found. The germination of *T. aestivum* seeds at 10 mg.ml^{-1} (infusion for 24 and 48 hours) was significantly lower than at 5 and 15 mg.ml^{-1}. At the same time, seed

Table 2 Effect of *Ailanthus altissima* extracts on germination *Lycopersicon esculentum* seeds – Tukey's HSD test

Nr.	Variants	Total germination (%)	Distribution of variants into groups depending on the confidence levels												
			α = 0.05 +/- limits 12.857					α = 0.01 +/- limits 15.1345				α = 0.001 +/- limits 16.2196			
			1	2	3	4	5	1	2	3	4	1	2	3	4
6	AJn 15	2.5	****					****				****			
9	AJl 15	3.5	****					****				****			
7	AJn 10	13.0	****					****				****			
10	AJl 10	15.3	****					****				****			
3	AM 15	37.8		****					****				****		
8	AJn 5	45.5		****	****				****	****			****	****	
4	AM 10	45.8		****	****				****	****			****	****	
11	AJl 5	48.5		****	****	****			****	****			****	****	
5	AM 5	56.8			****	****				****	****			****	****
2	Standard	59.5				****	****			****	****			****	****
1	Control	71.5					****				****				****

1, 2, 3, 4, and 5 – homogeneous groups without significant differences

germination when the extract from dried leaves was infused for 72 hours did not reveal a significant difference between all three concentrations – 5, 10, and 15 mg.ml^{-1} (Ullah et al., 2020). Studies by Sladonja et al. (2014) on the effect of extracts from ailanthus leaves on the germination of *Medicago sativa* L. seeds confirm our conclusions about a direct relationship between the concentration of extractives and seed germination (Sladonja et al., 2014). The results showed that at the maximum concentration (100%), seed germination was 30% lower than in the control, while dilutions of the extracts up to 80 and 60% showed a significantly lower decrease in germination compared to the control (Sladonja et al., 2014). A dose-dependent effect on *M. sativa* seed germination was also previously identified by Tsao et al. (2002), who showed that the crude extract from ailanthus leaves and stems significantly inhibited the germination of alfalfa seeds both in the dark and in the light (Tsao et al., 2002).

Other authors (Novak et al., 2021) analyzed the allelopathic effect of 3 different aqueous solutions based on extracts from the root of *A. altissima* (an aqueous solution of the root, an aqueous solution of isolated ailanthone, and an aqueous solution of the root without ailanthone) on the seeds of *Triticum aestivum* L., *Amaranthus retroflexus* L., and *Setaria pumila* L. The concentrated aqueous solution and dilutions of root and ailanthone were equivalent to a concentration of 0.48 mg.ml^{-1} ailanthone, before testing, the extracts were diluted with water in ratios of 1 : 4 and 1 : 16. A high allelopathic effect on radicle and shoot length of all test-species was proven for all investigated aqueous solution and their dilutions. The inhibitory effect on the initial growth of all test species was proportional to the increase in concentration in all treatments, which is consistent with our results. The effect on germination energy was stronger concerning the effect on the total germination of test species. Lower concentrations caused stimulation of *S. pumila* germination. *A. retroflexus* was the most sensitive and common wheat was the least sensitive test species. The least significant effect was measured in the aqueous solution of isolated ailanthone. Similar data were obtained by Tsao et al. (2002), who showed that, in addition to the crude extract from ailanthus, the fraction with methylene chloride also had a high inhibitory effect on the germination of alfalfa seeds at high concentrations, and a slight stimulating effect on the length of the radicles of germinated seeds at low concentrations (Tcao et al., 2002). The conclusions of these authors confirm our opinion about the inexpediency of isolating pure ailanthone from the crude extracts of ailanthus, since the purification method is quite energy- and labor-intensive.

As a result of our experiment, it was found that the allelopathic effect of the tested aqueous extracts of ailanthus on the germination of tomato seeds depended not only on the concentration of active components, but also on the time of collection of plant raw material. So, in the younger leaves of ailanthus, collected in May before flowering, most likely, substances responsible for inhibiting the germination of tomato seeds do not accumulate sufficiently. At the same time, we found that extracts from ailanthus leaves, collected in June during flowering, and extracts from ailanthus seeds, collected in July, exhibit a high allelopathic effect against to germination of tomato seeds. At the same time, the extract from the seeds is still inferior in efficiency to the extract from the leaves (Table 2). Thus, our data show that both ailanthus leaves collected in June and even completely unripe seeds already in July in the agro-climatic conditions of the Republic of Moldova accumulate sufficiently active components responsible for allelopathic properties.

Previously, as some authors have shown that extracts obtained from ailanthus roots or bark have the greatest allelopathic effect (Rehorska et al., 2014). Using a simple and effective bioassay as well as digital imaging and statistical analysis with free downloadable software, Rehorska et al. (2014) show that crude root extractives of *A. altissima* inhibit germination, radicle and hypocotyl growth of garden cress (*Lepidium sativum* L.) far more pronounced than leaf extractives (Rehorska et al., 2014). At the same time, other authors (Caser et al., 2020) showed that all parts of the ailanthus plant – the leaves, samaras, rachises, and secondary roots have high herbicidal properties in direct proportion to the content of ailanthone in them. Our data revealed that ailanthus leaves and seeds can also be successfully used to obtain plant extracts with high allelopathic properties (Figure 1, Table 2).

As a result of the experiments on studying the effect of ailanthus extracts on the germination of seeds of the cultivated plant *L. esculentum*, a rather high allelopathic effect was revealed. Novak et al. (2021) when studying the effect of aqueous extracts and their dilutions from young shoots with roots of heaven tree, collected in May before flowering, on the seeds of *Triticum aestivum* L., revealed a statistically significant inhibition of seed germination in comparison with the control (by 12.21%) only in variant with concentrated (100%) ailanthus root aqueous solution (Novak et al., 2021). Ulla et al. (2020) also found a 13.33% reduction in *T. aestivum* seed germination percentage compared to the control (100% germination) when using 10 g dry ailanthus leaf extract in 48 hours soaking duration (Ullah et al., 2020). From what has been described, we see that aqueous extracts from various parts of the ailanthus plant partially or significantly inhibit the germination of seeds of some cultivated plants. These facts indicate the absence of selective action in ailanthus extracts, the germination of seeds of not only weeds is suppressed, as reported by many authors (Rehorska et al., 2014; Caser et al., 2020; Ullah et al., 2020; Novak et al., 2021), but seed germination of crops such as tomatoes and common wheat is also suppressed.

Thus, it was found that the allelopathic effect of aqueous extracts from the leaves and seeds of ailanthus depended to a greater extent on the concentration of active substances than on the time of collection of plant raw material or on the parts of the ailanthus plant used. At the same time, it was found that the extract from young leaves collected in May before flowering has a less pronounced allelopathic effect in comparison with extracts from leaves collected in June and their seeds collected in July.

Some active compounds from *Ailanthus altissima* such as ailanthone, ailanthinone, chaparrine, and ailanthinol B (quassinoid derivatives) have been isolated (De Feo et al., 2003). It was found that the alkaloid 1-methoxycanthin-6 did not possess herbicidal activity against radish, garden cress, and purslane seeds (De Feo et al., 2003).

According to many authors, quassinoid ailanthone is one of the main active components responsible for the herbicidal activity of extracts from *Ailanthus altissima* (Demasi et al., 2019; Caser et al., 2020; Novak et al., 2021). Quassinoids are highly modified triterpenoids. Pedersini et al. (2011) showed that for the most extracts from the bark of the deciduous tree *Ailanthus altissima*, significant pre-emergence herbicidal activity was found, which directly correlated with the concentration of alanthone (Pedersini et al., 2011). These authors also presented the NMR study which moreover to identifying ailanthone as the predominant quassinoid with herbicidal activity in *A. altissima* extracts, showed additional structural data on ailanthone (Pedersini et al., 2011).

3.2 Allelopathy effect of aqueous extracts on seed radicle length

It was found that two of the three tested aqueous extracts from ailanthus, namely AJn and AJl, at a concentration of 15 mg.ml^{-1} of dry residue significantly (p ≤0.0005) inhibited the growth of the radicle as in comparison with the control (14.2–15.4 times or by 92.9–94.6%), and in comparison with the chemical standard (1.9–2.1 times or by 47.9–60.4%). AM extract at a concentration of 15 mg.ml^{-1} significantly inhibited the growth of tomato radicles only in comparison with the control – 5.5 times (or by 82.4%). The length of the radicles of germinated tomato seeds in the treatment with AM 5 extract was at the level of the chemical standard (Table 3, Figure 2.). With a decrease in the concentration of ailanthus extracts to 10 and 5 mg.ml^{-1}, the length of the radicles of tomatoes increased significantly, remaining, however, in most variants significantly less than in the control (Table 3). In the AM 5 variant, the length of radicles in germinated tomato seeds was at the control level, while the absolute value was even higher than the control one. Statistical analysis of the data (Tukey's HSD test, p ≤0.05) showed the distribution of variants depending on the length of the radicles of germinated tomato seeds by groups at different significance confidence levels (Table 3).

Thus, at the lowest concentration tested, an aqueous extract from ailanthus leaves harvested in May (AM)

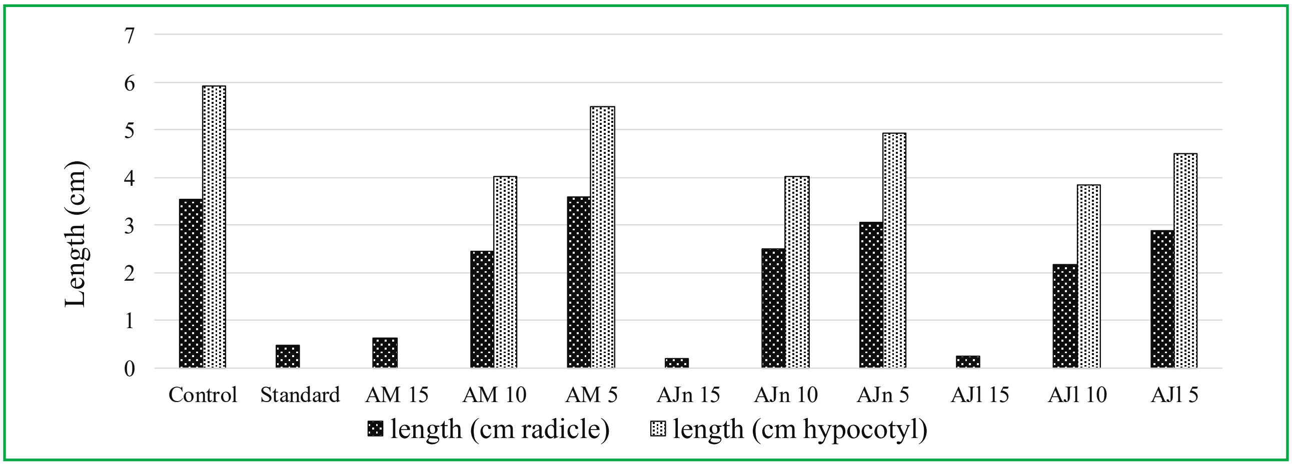

Figure 2 Allelopathic effect of aqueous extracts from *Ailanthus altissima* on the length of the radicle and hypocotyl of *Lycopersicon esculentum* seeds

not only did not suppress, but even stimulated (albeit insignificantly) in comparison with the control, the growth of germinated tomato radicles, despite the presence of an allelopathic effect in of this AM extract on seed germination. Our data are in good agreement with those previously obtained by other authors (Ullah et al., 2020), who showed that the inhibitory effect for the extract from both fresh and dry material on the *T. aestivum* radicle length is concentration dependent.

3.3 Allelopathy effect of aqueous extracts on seed hypocotyl length

It was revealed that all tested extracts from ailanthus at a concentration of 15 mg.ml^{-1} of extractive substances completely suppressed the germination of the hypocotyl in tomato seeds. This effect was also observed in the chemical standard (Figuree 2). Statistical analysis of the data (Tukey's HSD test, $p \leq 0.05$) showed the distribution of variants depending on the length of the radicles of germinated tomato seeds by groups for different significance confidence levels (Table 4).

According to the obtained data, the AM 5 extract had the least inhibitory effect on hypocotyl germination, the hypocotyl length for both significance levels $\lambda = 0.05$ and 0.01 was at the control level. Thus, the concentration of active substances in extracts has the most significant effect on the hypocotyl lengths. It was also found that extracts obtained from plant material collected in spring – in May, had the least pronounced allelopathic properties against to tomato seeds in all respects. This fact confirms that the secondary metabolites of ailanthus, responsible for the allelopathic effect, accumulate in the plant gradually during the season.

Previously Rehorska et al. (2014) observed that the hypocotyl growth rate and length of the *Lepidium sativum*

Table 3 Effect of *Ailanthus altissima* extracts on *Lycopersicon esculentum* radicle length – Tukey's HSD test

Variants	Length of radicle (cm)	$\alpha = 0.05$					$\alpha = 0.01$				
		1	2	3	4	5	1	2	3	4	5
AJn 15	0.23	****					****				
AJl 15	0.25	****					****				
Standard	0.48	****					****				
AM 15	0.64	****					****				
AJl 10	2.17		****					****			
AM 10	2.44		****					****	****		
AJn 10	2.53		****	****				****	****		
AJl 5	2.89			****	****				****	****	
AJn 5	3.06				****					****	
Control	3.54					****					****
AM 5	3.60					****					****

1, 2, 3, 4, and 5 – homogeneous groups without significant differences

Table 4 Effect of *Ailanthus altissima* extracts on *Lycopersicon esculentum* hypocotyl length – Tukey's HSD test

Variants	Length of hypocotyl (cm)	α = 0.05				α = 0.01			
		1	2	3	4	1	2	3	4
AJl 10	3.84	****				****			
AJn 10	4.02	****				****			
AM 10	4.02	****				****			
AJl 5	4.51	****	****			****	****		
AJn 5	4.94		****	****			****	****	
AM 5	5.49			****	****			****	****
Control	5.92				****				****

1, 2, 3, and 4 – homogeneous groups without significant differences

L. was less affected by both *A. altissima* leaf and root extracts than those of the radicles lengths (Rehorska et al., 2014). Ulah et al. (2020) revealed that the extract of fresh and dried leaves of *A. altissima* had a more pronounced inhibitory effect on the radicle and plumule length of *Triticum aestivum* compared to the germination percentage (Ullah et al., 2020). The extract from dry leaves at a concentration of 15 g, in 48 hours soaking duration, reduced the radicle length of the *T. aestivum* up to 0.67 mm, as compared to the control (18.2 mm). The extract from dry leaves at a concentration of 10 g, in 48 hours soaking duration, reduced the plumule length by 0.26 mm as compared to the control (7.8 mm) (Ullah et al., 2020). Our data show that ailanthus extracts primarily significantly affect the hypocotyl length of tomato seeds. Although such parameters as germination and length of tomato radicles were also significantly affected by the influence of extracts in direct proportion to their concentration.

4 Conclusions

The germination energy and total germination rate of tomato seeds, as well as the length of radicles and hypocotyls of germinated seeds, most significantly decreased when treated with aqueous extracts from ailanthus leaves collected in June during flowering, and from seeds collected in July, at a concentration of 10 and 15 mg.ml^{-1} of dry residue. At the same time, the total germination rate of seed was suppressed on average by 56.2–69.0% in comparison with the control and by 44.2–57.0% in comparison with the chemical standard. The radicle length of seeds treated with ailanthus extracts decreased 1.4–18.6 times (by 28.9–94.6%) in comparison with the control. Hypocotyl growth at 15 mg.ml^{-1} was completely suppressed in all three tested ailanthus extracts. The inhibitory effect of aqueous extracts decreased in direct proportion with a decrease in the concentration of active substances contained in extracts. The most susceptible influence of ailanthus extracts was on the hypocotyl growth of tomato seeds. It was concluded that the leaves and immature seeds of *Ailanthus altissima* contain potential allelopathic substances that affect the energy of germination, and total germination rate, and inhibit the hypocotyl and radicle length of tomatoes. Therefore, aqueous extracts of ailanthus should be used to protect tomato fields from weeds with caution and only in the post-emergence period, when the plants are strong enough.

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References

Albouchi, F. et al. (2013). Phytochemicals, antioxidant, antimicrobial and phytotoxic activities of *Ailanthus altissima* (Mill.) Swingle leaves. *South African Journal of Botany*, 87, 164–174. https://doi.org/10.1016/j.sajb.2013.04.003

Boer, E. (2013). *Risk assessment Ailanthus altissima* (Mill.) *Swingle*. Leiden: Naturalis Biodiversity Center (20 p.).

Bralewski, T.W. et al. (2004). Indexes of tolerance of tomato (*Lycopersicon esculentum* Mill.) seeds for germination at low temperatures. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 32(1), 35-42. https://doi.org/10.15835/nbha321184

Caser, M. et al. (2020). Activity of *Ailanthus altissima* (Mill.) Swingle Extract as a Potential Bioherbicide for Sustainable Weed Management in Horticulture. *Agronomy*, 10(7), 965. https://doi.org/10.3390/agronomy10070965

Constan-Nava, S. et al. (2015). Direct and indirect effects of invasion by the alien tree *Ailanthus altissima* on riparian plant communities and ecosystem multifunctionality. *Biology Invasions*, 17, 1095–1108. https://doi.org/10.1007/s10530-014-0780-4

De Feo, V. et al. (2003). Isolation of Phytotoxic Compounds from Tree-of-Heaven (*Ailanthus altissima* Swingle). *Journal of Agricultural and Food Chemistry*, 51(5), 1177–1180. https://doi.org/10.1021/jf020686%2B

De Feo, V. et al. (2009). Bioassay-oriented isolation of an insecticide from *Ailanthus altissima*. *Journal of Plant Interactions*, 4(2), 119-123. https://doi.org/10.1080/17429140802503343

Demasi, S. et al. (2019). Ailanthone inhibition data on seed germination and seedling growth of *Lepidium sativum* L. and *Raphanus sativus* L. *Data in Brief*, 26, 104550. https://doi.org/10.1016/j.dib.2019.104550

Fotiadis, G., Kyriazopoulos, A.P., & Fraggakis, I. (2011). The behaviour of *Ailanthus altissima* weed and its effects on natural ecosystems. *Journal of Environmental Biology*, 32(6), 801–806.

Galasso, G. et al. (2018). An updated checklist of the vascular flora alien to Italy. Plant Biosystems. *International Journal Dealing with all Aspects of Plant Biology*, 152(3), 556–592. https://doi.org/10.1080/ 11263504.2018.1441197

Hoshovsky, M.C. (1988). Element Stewardship Abstract for *Ailanthus altissima*, Tree-of-Heaven. The Nature Conservancy, Arlington, Virginia (13 p.).

Huang, T.C., & Editorial Committee of the Flora of Taiwan (2003). *Flora of Taiwan.* (2nd ed.). Department of Botany, National Taiwan University, (343 p.).

International Rules for Seed Testing (ISTA). (2023). Chapter 1, i–1-14 (22). https://doi.org/10.15258/istarules.2023.01

Ivanova, R., & Elisovetcaia, D. (2018). Biologicheskiye pestitsidy – rasteniya dlya zashchity rasteniy [Biological pesticides – plants for plant protection]. In Iu. Vinogradova, J. Brindza (eds.), *Publication for Specialized Courses of the International Project FarmersEduca – Neglected and Underutilized Species in the Social Economic Rural Development, Nitra.* Slovak Agrarian University in Nitra (pp. 11–12). Retrieved May 1, 2023 from https://agrobionet.uniag.sk/flipbkTB08_RU

Kasson, M.T., Davis, M.D., & Davis, D.D. (2013). The invasive *Ailanthus altissima* in Pennsylvania: a case study elucidating species introduction, migration, invasion, and growth patterns in the northeastern US. *Northeastern Naturalist*, 20(10), 1–60. http://www.bioone.org/doi/full/10.1656/045.020.m101

Kowarik, I., & Saumel, I. (2007). Biological Flora of Central Europe: *Ailanthus altissima* (Mill.) Swingle. *Perspectives in Plant Ecology, Evolution and Systematics*, 8, 207–237. http://dx.doi.org/10.1016/j.ppees.2007.03.002

Kozuharova, E. et al. (2022). Assessment of the Potential of the Invasive Arboreal Plant *Ailanthus altissima* (Simaroubaceae) as an Economically Prospective Source of Natural Pesticides. *Diversity*, 14, 680. https://doi.org/10.3390/d14080680

Novak, M. (2019). *Allelopathic potential of invasive alien species tree of heaven* (*Ailanthus altissima* (Mill.) Swingle). doctoral thesis, University of Zagreb, Fuculty of Agriculture (122 p.).

Novak, M., Novak, N., & Milinović, B. (2021). Differences in allelopathic effect of tree of heaven root extracts and isolated ailanthone on test-species. *Journal of Central European Agriculture*, 22(3), 611–622. https://doi.org/10.5513/JCEA01/22.3.3098

Pedersini, C. et al. (2011). Herbicide Activity of Extracts from *Ailanthus altissima* (Simaroubaceae). *Natural Product Communications*, 6(5), 593–596. https://doi.org/10.1177/1934578X1100600504

Poljuha, D. et al. (2017). Phenolic composition of leaf extract of *Ailanthus altissima* (Simaroubaceae) with antibacterial and antifungal activity equivalent to standard antibiotics. *Natural Product Communications*, 12 (10), 1609–1612. https://doi.org/10.1177/1934578X1701201

Rebbeck, J., & Jolliff, J. (2018). How long do seeds of the invasive tree, *Ailanthus altissima* remain viable? *Forest Ecology and Management*, 429(1), 175-179. https://doi.org/10.1016/j.foreco.2018.07.001

Rehorska, R. et al. (2014). Effects of *Ailanthus altissima* (Mill.) Swingle root and leaf extractives on germination, radicle and hypocotyl growth of garden cress (*Lepidium sativum* L.). *Phyton*, 54(2), 333–342. https://doi.org/10.12905/0380.phyton54(2)2014-0333

Sladonja, B. et al. (2014). Herbicidal effect of *Ailanthus altissima* leaves water extracts on *Medicago sativa* seeds germination. *3rd Conference with International Participation VIVUS – on Agriculture, Environmentalism, Horticulture and Floristics, Food Production and Processing and Nutrition, Transmission of Innovations, Knowledge and Practical Experience into Everyday Practice*, Naklo, Slovenia, 14–15 November (pp. 476–481).

Sladonja, B., Sušek, M., & Guillermic, J. (2015). Review on invasive tree of heaven (*Ailanthus altissima* (Mill.) Swingle) conflicting values: assessment of its ecosystem services and potential biological threat. *Environmental Management*, 56(4), 1009–1034. https://doi.org/10.1007/s00267-015-0546-5

Tanasković, S. et al. (2021). Antifeeding and Insecticidal Activity of *Ailanthus altissima* and Morus alba Extracts Against Gipsy Moth (*Lymantria dispar* (L.), Lepidoptera, Lymantridae) Larvae Under Laboratory Conditions. *Journal of the Entomological Research Society*, 23(3), 197–212. https://doi.org/10.51963/jers.v23i3.1989

The European Commission's food safety. (2023). *Approval of active substances, Renewal of approval, Glyphosate*. https://food.ec.europa.eu/plants/pesticides/approval-active-substances/renewal-approval/glyphosate_en

The state register of phytosanitary products and fertilizers [Registrul de stat al produselor fitosanitare și al îngrășămintelor]. (2022). Chisinau. https://www.pesticide.md/registrul-de-stat/

Tsao, R. et al. (2002). Plant growth regulatory effect and insecticidal activity of the extracts of the Tree of Heaven (*Ailanthus altissima* L.). *BMC Ecology*, 2(1). https://doi.org/10.1186/1472-6785-2-1

Ullah, Z. et al. (2020). Allelopathic effect of *Ailanthus altissima* on wheat (*Triticum aestivum* L.). *Pure Applied Biology*, 9(1), 309–319. http://dx.doi.org/10.19045/bspab.2020.90036

Weber, E. (2003). Invasive Plant Species of the World: A Reference Guide to Environmental Weeds. UK, Wallingford: CABI International, 548.

Weber, E., & Gut, D. (2004). Assessing the risk of potentially invasive plant species in Central Europe. *Journal of Nature Conservation*, 12, 171–179. https://doi.org/10.1016/j.jnc.2004.04.002

Yonebayashi, C., Arai, Y., & Higa, M. (2016). Shoot recovery of *Ailanthus altissima* from cutting and fire disturbance in a riverside park in central Japan. *Vegetation Science*, 33(2), 81–87. https://doi.org/10.15031/vegsci.33.81