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ORIGINAL ARTICLE

Seedlings growing from the seeds/achenes of *Amorpha fruticosa* L. tolerate salinity stress in different way

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Abstract
Amorpha fruticosa is a fastgrowing shrub that is often planted along motorways. The aim of this article was to clarify the level of salinity stress that can be tolerated by seedlings growing from seeds or fruits of *A. fruticosa*. Germination tests were carried out in laboratory conditions, using seeds with and without a pericarp (fruit and seed) in 6 different solutions with content of NaCl 0%, 0.12%, 0.25%, 0.50%, 0.99% and 1.96%. The germination of fruits was delayed compared to seeds. Seeds germinated well in 0.12%, 0.25%, 0.50% and 0.99% NaCl treatments, and fruits germinated well in the 0.12%; 0.25% and 0.50% NaCl treatments (comparable to the control). Conversely, significant differences were found in the growth of seedlings from fruits treated with 0.99% and 1.96% NaCl and seeds treated with 1.96% NaCl. Both seeds and fruits of *A. fruticosa* are tolerant to increased NaCl content in solution and can grow into viable seedlings.

Keywords Forestry · Halophyte · Invasive species · Production shrub · Salinity

Introduction

Soil salinization and the associated land degradation threaten ecosystems, biodiversity, and human populations in semiarid and arid regions. It is a global issue affecting large regions, especially in Asia, Africa, and Australia (Hassani et al. 2020). Soil salinization belongs among the most serious threats to agriculture and the food security (Tarolli et al. 2024). Salinization is also contributed to by climate change, which is expected to cause further expansion of affected areas by 2100 (Hassani et al. 2021). Therefore, it is important to know the spatio-temporal distribution of salt-affected soils and to identify plant species that are tolerant or resistant to salinization (Hassani et al. 2020; Tlahig et al. 2021). One possibility for improving the current situation is the revegetation of affected soils with stress-tolerant species, such as *Amorpha fruticosa* (Cao et al. 2020).

A. fruticosa (Fabaceae) is a woody plant native to North America. It has secondarily spread to countries in South America, Asia, and Europe (Verloove 2006; Pyšek et al. 2022; Lapin and Dyderski 2024; Powo 2024). In European and Asian countries, it is mostly considered invasive (EPPO 2024). This is a deciduous shrub growing to a height of 1–4 (6) meters, with an extensive root system (Wang et al. 2011; Dřevojan et al. 2022; Jiang et al. 2025). It is light- and heat-demanding, capable of tolerating moderate soil salinity (Chytrý et al. 2018). It reproduces both sexually and vegetatively (Kolyada and Kolyada 2018; Šerá et al. 2024).

Thanks to its broad ecological amplitude, it can invade various habitat types. It most commonly occurs in wet and periodically flooded sites with both forested and nonforested vegetation (Radovanović et al. 2017). Its rapid growth, root structure, and salinity tolerance make it suitable for planting on roadside embankment slopes, revegetation of bare soils, semiarid lands with secondary salinization, and abandoned mining areas (Seo et al. 2008; Feng et al. 2015; Chen et al. 2023).

In saline soils, plants are exposed to stress that affects photosynthesis and hormonal regulation, causes nutritional imbalance, specific ion toxicity and osmotic effects (Farooq et al. 2017). The pericarp and seed coat

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Table 1 Characteristics of the collection sites for *A. fruticosa* fruits

Location	Bratislava	Lučenec	Púchov
Coordinates	48°08′54.17″, 17°04′17.11″	48°20′04.33″, 19°38′42.58″	49°06′56", 18°18′57"
Description of habitat	built-up area, road embankment slope	built-up area, road embankment slope	built-up area, road embankment slope
Altitude	159 m a.s.l.	209 m a.s.l.	260 m a.s.l.
Expozition	S	NW	NW
Slope	30°	35°	20°
Geomorfological unit (Mazúr and Lukniš 1986)	Malé Karpaty Mts	Lučenská kotlina basin	Javorníky Mts
Climatic region* (Lapin et al. 2002)	Warm region, 50 or more summer days annually in average	Warm region, 50 or more summer days annually in average	Moderately warm region, less than 50 summer days annually in average and the July temperature 16 °C or more
Mean annual precipitation total (Faško and Šťastný 2002)	600–700 mm	550–600 mm	700–800 mm

*all climatic regions with summer daily maximum air temperature ≥ 25 °C

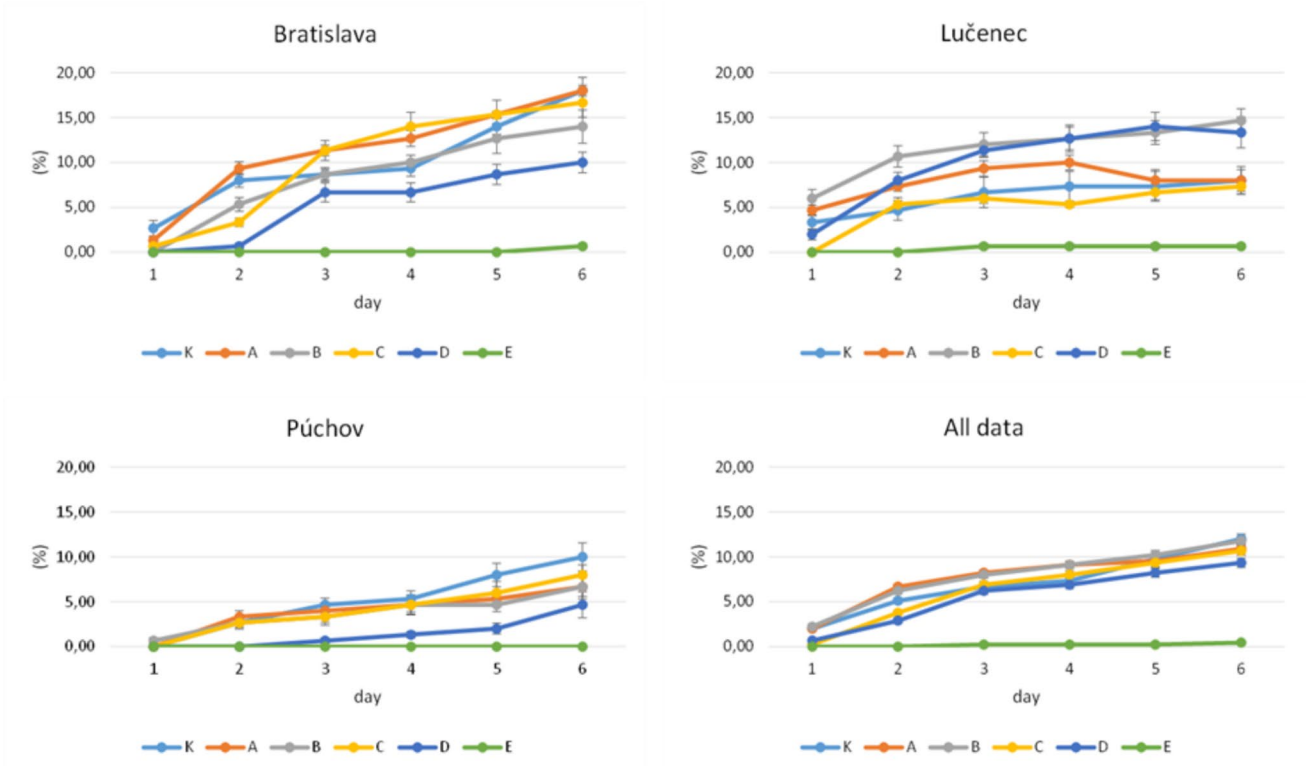


Fig. 1 Seed germination of *A. fruticosa* (obtained from seeds) in relation to the salinity. NaCl solutions used: K 0%, A 0.12%, B 0.25%, C 0.50%, D 0.99%, and E 1.96%; mean and SE are given

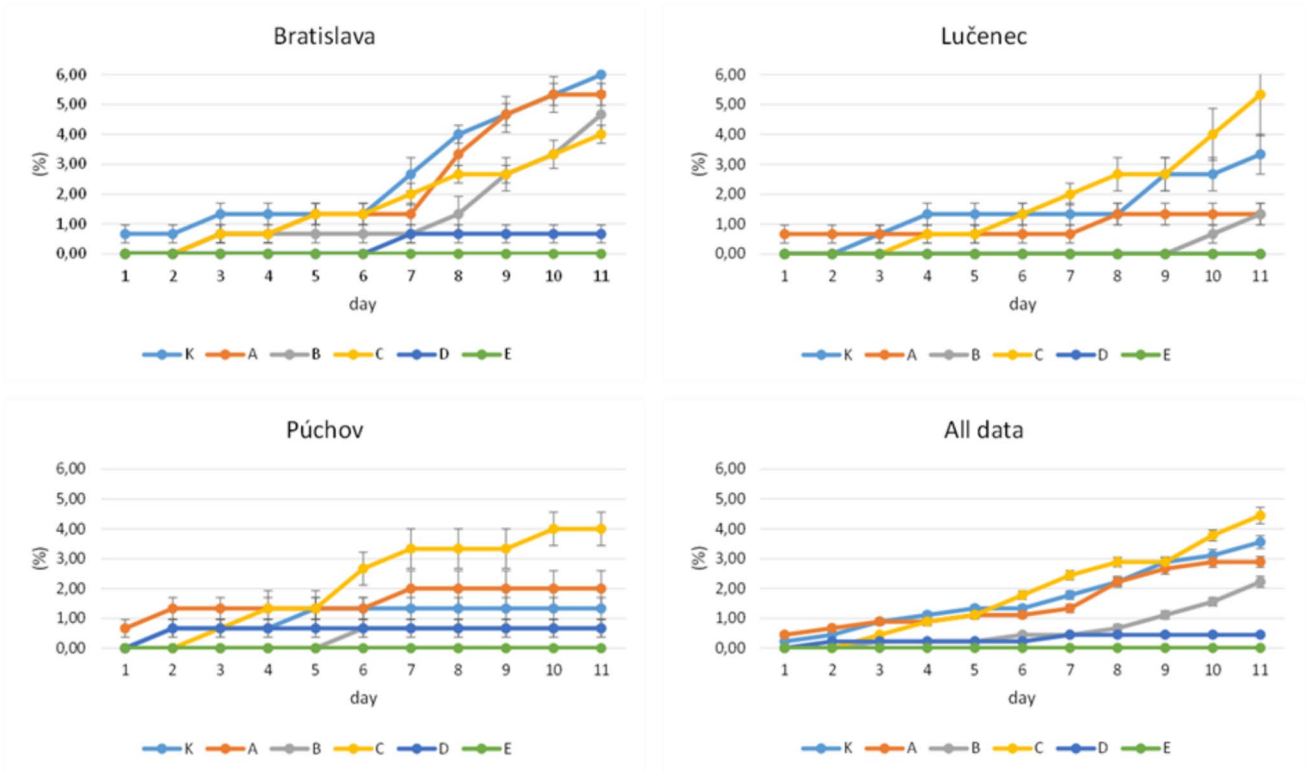


Fig. 2 Seed germination of *A. fruticosa* (obtained from fruits) in relation to the salinity. NaCl solutions used: K 0%, A 0.12%, B 0.25%, C 0.50%, D 0.99%, and E 1.96%; mean and SE are given

act as barriers influencing the penetration of salt into seeds (Koyro and Eisa 2008; Gao et al. 2025). In our experiment we determined the tolerance level of *A. fruticosa* to sodium chloride (NaCl) in aqueous solution separately for seeds with pericarp (achenes) and seeds without pericarp.

Materials and methods

Fruit Collection of *A. fruticosa*

Fruit (achene) collection of *A. fruticosa* took place in the cities of Bratislava, Lučenec, and Púchov in September 2023 (Table 1). At each location, three plant individuals of varying heights and fertility were randomly selected for fruit collection. The individuals were growing at a distance of 2–3 m from the road edge. The distance between them was up to 2 m.

Fruit and seed quality

The collected fruits were dried at room temperature, and mechanically or pest-damaged fruits were excluded. Half of the fruits from each location (more than 1 000 units) had their pericarps removed, yielding samples of seeds without pericarp.

Experimental design

The methodological basis of the experiment was the work of Šerá (2023). The experiment was conducted twice, separately for fruits and seeds of *A. fruticosa*. For each experiment, 5 Petri dishes with a single filter paper were used for one treatment. Each Petri dish contained 30 fruits/seeds, totaling 150 fruits/seeds per treatment, 900 fruits/seeds per location, and 2 700 fruits and 2 700 seeds for entire design.

Six milliliters of NaCl solution were added to each dish. The content levels of NaCl solutions were: K (control): 0%, A: 0.12%, B: 0.25%, C: 0.50%, D: 0.99%, E: 1.96%. During the germination period, the propagules were watered as needed with a defined volume of distilled water to prevent drying. The Petri dishes were stored in darkness at a constant temperature of 22 °C in a thermostat. Propagules affected by mold during the experiment were removed.

Table 2 Characteristics of *A. fruticosa* seeds in relation to the salinity on the 6th day

Location	Treatment	Seed germination (%) 6th day			Seedling length (mm) 6th day			Seedling vitality index I. (mm) 6th day		
		Mean	SE	PHC	Mean	SE	PHC	Mean	SE	PHC
Bratislava	K	18.00	3.27	a	1.55	0.33	ad	31.24	8.49	a
	A	18.00	1.33	a	2.10	0.35	a	38.73	8.21	a
	B	14.00	4.14	a	1.43	0.26	ad	23.22	10.34	c
	C	16.67	3.65	a	1.18	0.22	cd	22.73	8.54	c
	D	10.00	2.58	a	0.41	0.12	bc	5.18	1.65	bc
	E	0.67	0.67	b	0.01	0.01	bc	0.02	0.02	b
Lučenec	K	8.00	3.43	ab	1.12	0.59	ac	17.02	12.22	ab
	A	8.00	2.71	ab	1.02	0.38	ac	12.22	5.46	ab
	B	14.67	2.91	a	1.89	0.42	a	31.76	11.56	a
	C	7.33	1.94	ab	0.43	0.15	c	4.22	2.41	b
	D	13.33	3.80	ab	0.85	0.26	c	15.07	8.55	ab
	E	0.67	0.67	b	0.01	0.01	b	0.04	0.04	b
Púchov	K	10.00	3.50	a	0.77	0.19	a	9.42	4.64	a
	A	6.67	2.98	a	0.47	0.18	a	4.98	2.86	a
	B	6.67	2.36	a	0.44	0.23	a	4.91	3.16	a
	C	8.00	2.49	a	0.46	0.25	a	6.11	4.41	a
	D	4.67	3.27	a	0.05	0.04	a	0.76	0.65	a
	E	0.00	-	-	0.00	-	-	0.00		-
All data	K	12.00	2.15	a	1.15	0.23	a	19.23	5.38	a
	A	10.89	1.88	a	1.20	0.25	a	18.64	5.01	a
	B	11.78	1.98	a	1.26	0.23	a	19.96	5.73	a
	C	10.67	1.87	a	0.69	0.15	c	11.02	3.78	ab
	D	9.33	1.98	a	0.44	0.12	bc	7.00	3.13	ab
	E	0.44	0.30	b	0.01	0.00	b	0.02	0.02	b

NaCl solutions used: K 0%, A 0.12%, B 0.25%, C 0.50%, D 0.99%, and E 1.96%; mean, standard error (SE) andpost-hoc comparison (PHC) are given; PHC: different letters indicate significant differences ($P < 0.05$)

We focused on determining the following basic parameters: seed germination, seedling length and seedling vitality index I. All these three characteristics were recorded for 6 days for seeds without the pericarp and 11 days for seeds with the pericarp. In the following text we will strictly distinguish between the characteristics obtained from fruits (seeds with the pericarp) and from seeds (seeds without the pericarp).

Data analysis

The values of all three variables were recorded for each day, so it was possible to create dynamic graphs (time course) for each location separately (designation used: Bratislava, Lučenec, Púchov). At the same time, all data from the locations were merged into one file. It was therefore possible to visualize the trends of all three variables from a robust data set (designation used: All data).

The data from the last day of the test were processed using the statistical software package STATISTICA (Dell Inc., 2016). A one-way analysis of variance (ANOVA) was applied, followed by Duncan's test (post-hoc comparison, PHC) to compare the individual treatments from the last day of the measurements. Statistical calculations were performed at a significance level of $\alpha < 0.05$.

Results

Seed germination

Neither seeds nor fruits germinated at the highest NaCl content used (E, 1.96%), therefore we also did not obtain data for seedling length and seedling vitality index I.

The germination kinetics of seeds and fruits are shown in Figs. 1 and 2, respectively. The seeds started

Table 3 Characteristics of *A. fruticosa* fruits in relation to the salinity on the 6th day

Location	Treatment	Seed germination (%) 6th day			Seedling length (mm) 6th day			Seedling vitality index I. (mm) 6th day		
		Mean	SE	PHC	Mean	SE	PHC	Mean	SE	PHC
Bratislava	K	1.33	0.82	a	0.29	0.21	a	0.98	0.69	a
	A	1.33	0.82	a	0.13	0.10	a	0.42	0.32	a
	B	0.67	0.67	a	0.10	0.10	a	0.33	0.33	a
	C	1.33	0.82	a	0.09	0.07	a	0.31	0.22	a
	D	0.00	-	-	0.00	-	-	0.00	-	-
	E	0.00	-	-	0.00	-	-	0.00	-	-
Lučenec	K	1.33	0.82	a	0.16	0.10	a	0.53	0.34	a
	A	0.67	0.67	a	0.16	0.16	a	0.53	0.53	a
	B	0.00	-	-	0.00	-	-	0.00	-	a
	C	1.33	0.82	a	0.05	0.04	a	0.18	0.13	a
	D	0.00	-	-	0.00	-	-	0.00	-	-
	E	0.00	-	-	0.00	-	-	0.00	-	-
Púchov	K	1.33	0.82	a	0.21	0.17	a	0.71	0.56	a
	A	1.33	0.82	a	0.39	0.25	a	1.31	0.82	a
	B	0.67	0.67	a	0.01	0.01	a	0.04	0.04	a
	C	2.67	1.25	a	0.20	0.17	a	1.24	1.13	a
	D	0.67	0.67	a	0.10	0.10	a	0.33	0.33	a
	E	0.00	-	-	0.00	-	-	0.00	-	-
All data	K	1.33	0.44	a	0.22	0.09	a	0.74	0.30	a
	A	1.11	0.42	a	0.23	0.10	a	0.76	0.33	a
	B	0.44	0.30	ca	0.04	0.03	ab	0.13	0.11	a
	C	1.78	0.55	d	0.12	0.06	ab	0.58	0.38	a
	D	0.22	0.22	b	0.03	0.03	ab	0.11	0.11	a
	E	0.00	-	b	0.00	-	-	0.00	-	-

NaCl solutions used: K 0%, A 0.12%, B 0.25%, C 0.50%, D 0.99%, and E 1.96%; mean, standard error (SE) andpost-hoc comparison (PHC) are given; PHC: different letters indicate significant differences ($P < 0.05$)

to germinate earlier (3rd day) than the fruits (6th day). The highest seed germination values were recorded for sets originating from Bratislava; seeds reached max 18% and fruits max 6%. Data combined from all three sites (All data) showed that on the sixth day the seeds reached higher germination values (max 12%, control set) than the fruits (max 1.78%, treatment C).

Significant differences in seed germination are summarized in Tables 2, 3, 4. Seed germination values obtained from sets treated with lower amounts of NaCl were comparable to the control set, or even higher. Data combined from all three locations (All data) provide high informative value, where only treatment E (1.96% NaCl) differs significantly from the other treatments (including the control). For seed germination (obtained from fruits), it was found in the All data set that treatment C (0.50%) has the highest value and was also significantly different from the control. Germination values for treatment C were 1.78% on day 6 and 4.44% on day 11 (control set: 1.33% and 3.56%, respectively).

Seedling length

The kinetics of seedling length of seeds and fruits are shown in Figs. 3 and 4, respectively. The highest values of seedling length during growth were recorded in treatment A (0.12% NaCl) of seeds originating from Bratislava and fruits originating from Púchov and control set from Bratislava, respectively.

On the last day of the test, the highest values of seedling length were recorded in treatment A (0.12% NaCl) of seeds originating from Bratislava (2.10 mm) and of fruits originating from Púchov (1.13 mm), and Bratislava (1.16 mm, control set). These recorded values were not significantly

Table 4 Characteristics of *A. fruticosa* fruits in relation to the salinity on the 11th day

Location	Treatment	Seed germination (%) 11th day			Seedling length (mm) 11th day			Seedling vitality index I. (mm) 11th day		
		Mean	SE	PHC	Mean	SE	PHC	Mean	SE	PHC
Bratislava	K	6.00	1.25	a	1.16	0.40	a	6.18	1.55	a
	A	5.33	0.82	a	0.94	0.36	ab	5.82	2.61	a
	B	4.67	1.33	a	0.59	0.40	ab	4.91	4.27	a
	C	4.00	0.67	ab	0.58	0.18	b	2.22	0.60	a
	D	0.67	0.67	b	0.04	0.04	b	0.13	0.13	a
	E	0.00	-	-	0.00	-	-	0.00	-	-
Lučenec	K	3.33	1.49	ab	0.52	0.27	a	3.29	1.85	a
	A	1.33	0.82	a	0.33	0.26	a	1.09	0.86	a
	B	1.33	0.82	a	0.05	0.03	a	0.16	0.11	a
	C	5.33	3.09	b	0.39	0.21	a	4.44	3.10	a
	D	0.00	-	-	0.00	-	-	0.00	-	-
	E	0.00	-	-	0.00	-	-	0.00	-	-
Púchov	K	1.33	0.82	a	0.77	0.48	ab	2.56	1.59	a
	A	2.00	1.33	a	1.13	0.70	a	5.89	4.13	a
	B	0.67	0.67	a	0.13	0.13	b	0.44	0.44	a
	C	4.00	1.25	a	0.73	0.35	ab	4.47	2.48	a
	D	0.67	0.67	a	0.17	0.17	ab	0.56	0.56	a
	E	0.00	-	-	0.00	-	-	0.00	-	-
All data	K	3.56	0.83	a	0.82	0.22	a	4.01	0.98	a
	A	2.89	0.72	a	0.80	0.27	a	4.27	1.65	a
	B	2.22	0.70	dc	0.26	0.15	bc	1.84	1.45	b
	C	4.44	1.06	e	0.57	0.14	ac	3.71	1.27	a
	D	0.44	0.30	bc	0.07	0.06	b	0.23	0.19	b
	E	0.00	-	b	0.00	-	-	0.00	-	-

NaCl solutions used: K 0%, A 0.12%, B 0.25%, C 0.50%, D 0.99%, and E 1.96%; mean, standard error (SE) andpost-hoc comparison (PHC) are given; PHC: different letters indicate significant differences ($P < 0.05$)

different from the control sets (Tables 2, 3, 4). Significant differences from the controls were usually recorded in treatments with higher amounts of NaCl, such as C and D (0.50% and 0.99%, respectively) (Tables 2, 3, 4).

Seedling vitality index I

The trend of changes in the seedling vitality index I. values over time is shown in Figs. 5 and 6. The values of the seedling vitality index I. during seed growth were highest in treated seeds A (0.12% NaCl) originating from Bratislava and B (0.25% NaCl) originating from Lučenec. In fruits, the highest growth of this index was obvious in control set from Bratislava and set A (0.12% NaCl) from Púchov.

On the last day of the test, the highest values of the seedling vitality index I. were recorded in seeds 38.73 mm and 31.76 mm (A, 0.12% NaCl, Bratislava, B, 0.25% NaCl, Lučenec) and in fruits 6.18 mm and 5.89 mm (control from Bratislava, A 0.12% NaCl, Púchov), while the values of the treatments did not differ significantly from the control (Tables 2, 3, 4). Significant differences from controls were noted for fruits in the All data set, where treatments B and D (0.25% and 0.99%, respectively) were significantly lower than the control ($P < 0.05$, Table 4).

Discussion

The effect of NaCl on seed and fruit germination of *A. fruticosa* was studied by Đukić et al. (2010). They used two samples of fruits. One sample was from the inundation area of the Sava River (where there was higher soil moisture),

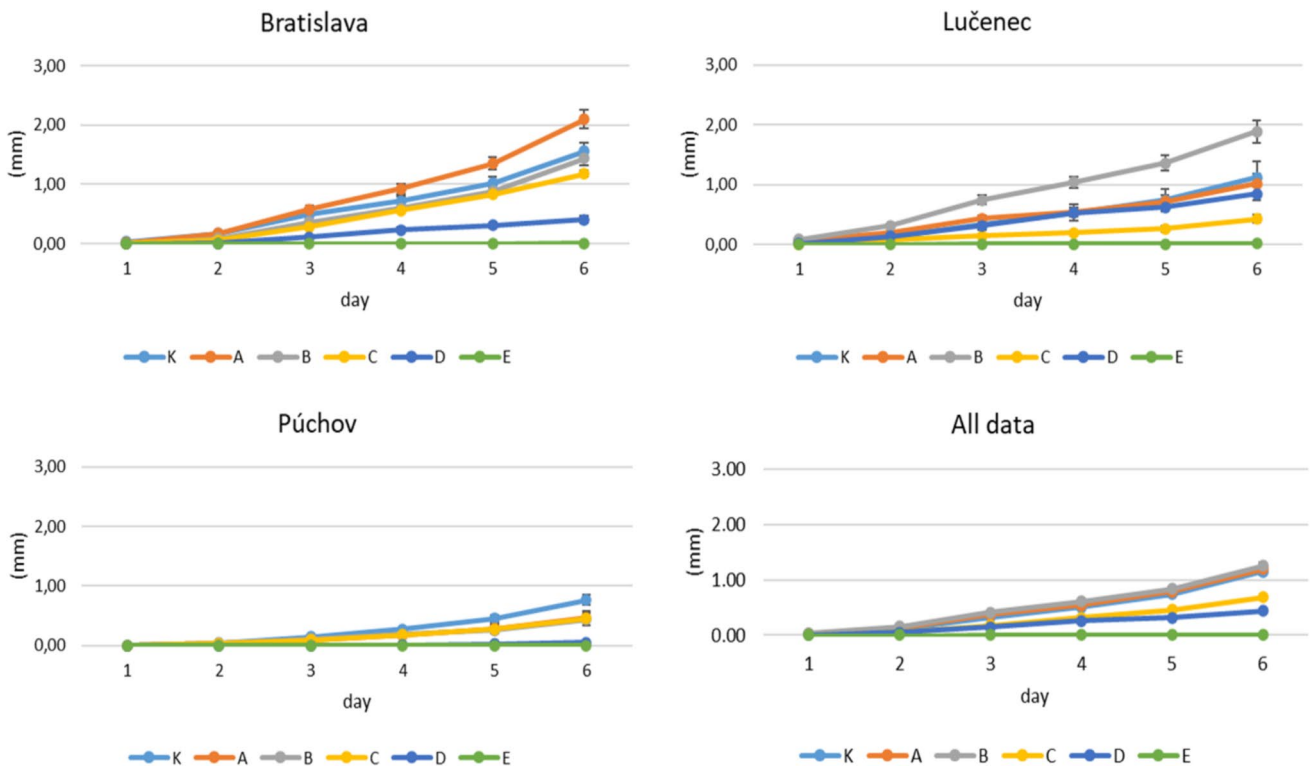


Fig. 3 Seedling length of *A. fruticosa* (obtained from seeds) in relation to the salinity. NaCl solutions used: K 0%, A 0.12%, B 0.25%, C 0.50%, D 0.99%, and E 1.96%; mean and SE are given

and the other from the roadside (where there was lower soil moisture). The highest germination rate for seeds and scarified fruits was observed in the control variants. Their results correspond with our findings for seeds from the Bratislava and Púchov locations and fruits from the Bratislava location. An exception was the germination of seeds and fruits from the Lučenec location, which achieved the highest germination in a 0.25% NaCl solution (seeds) and a 0.5% NaCl solution (fruits).

Đukić et al. (2010) found zero germination for fruits from both sites and for scarified fruits from the roadside in a solution containing 3000 ppm NaCl (= 0.3%). The NaCl content of 3000 ppm in our experiment would correspond to the NaCl content between variants B (0.25%) and C (0.50%). Contrary to their findings, we observed the highest germination in a 0.5% NaCl solution for fruits from the Lučenec and Púchov locations and zero germination for samples in a 1.96% NaCl solution (Table 4).

Đukić et al. (2010) also reported that scarified fruits from the inundation area germinated even in a solution containing 3000 ppm NaCl. This implies that *A. fruticosa* seeds from floodplain areas have higher germination rate and are more resistant to elevated concentration of NaCl. The influence of flooding on the germination of the seeds we studied can be excluded, as none of the fruit samples from our collection sites originated from the inundation area of a watercourse. A common characteristic of all three of our collection sites is that they are slopes adjacent to roadways. Their soils are influenced by salt from road maintenance. The differences between our results and those reported by Đukić et al. (2010) may be related to population differences, varying degrees of soil salinity at the sampling sites, or methodological differences.

The ability of *A. fruticosa* to tolerate soil salinity and its germination ability in saline-alkali habitats is also reported by Gao et al. (2024). They experimentally demonstrated the inhibitory effect of NaCl on the germination of seeds in NaCl solutions with concentrations of 0, 50, 100, 150, and 200 mmol.l^{-1} (NaCl content in solution 0; 0.29; 0.58; 0.87; and 1.16%). They observed a linear decrease in seed

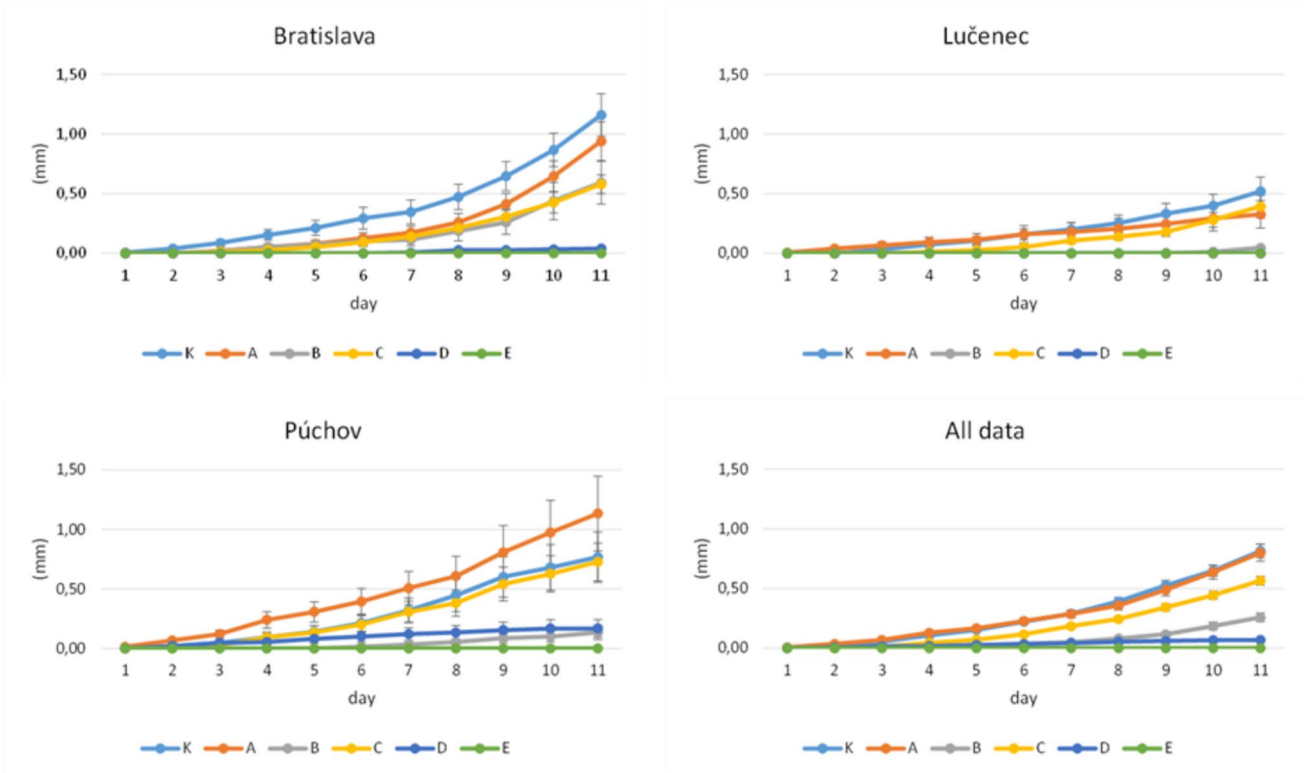


Fig. 4 Seedling length of *A. fruticosa* (obtained from fruits) in relation to the salinity. NaCl solutions used: K 0%, A 0.12%, B 0.25%, C 0.50%, D 0.99%, and E 1.96%; mean and SE are given

germination with increasing NaCl concentration. Nevertheless, germination of *A. fruticosa* seeds was recorded at all NaCl solution concentrations, including 200 mmol.l^{-1}. The authors also found that an appropriate salt content in the solution can promote the germination of *A. fruticosa* seeds. This was confirmed in our case for fruits from the Lučenec and Púchov locations, where the highest germination was observed in a solution containing 0.5% NaCl (Table 4), and for seeds in a 0.25% NaCl solution (Lučenec location, Table 2).

Guo et al. (2018) evaluated the relationship of *A. fruticosa* to salinity based on biomass production in environments uncontaminated and contaminated with NaCl. They found that biomass production in NaCl-contaminated environments decreased only slightly, providing further evidence of the species' tolerance to increased soil salinity.

In our comparison of germination of seeds to fruits, the germination of seeds was more intense (Figs. 1,2). Similar findings are reported by Šerá et al. (2024) through a study on the reproductive capacity of *A. fruticosa*. It is generally known that the pericarp, in addition to its protective function, also acts as a barrier slowing the onset of germination (Lu et al. 2015; Tan et al. 2022). As mentioned above, the effect of the pericarp on the germination of *A. fruticosa* seeds was studied by Đukić et al. (2010) and Gao et al. (2025). Similar to our experiment, their findings also showed higher germination rates for scarified fruits and seeds compared to fruits. An example of natural pericarp disruption is the trophic relationship between the plant and birds of the genus *Parus* (titmice, tits). By consuming the fruits and subsequently passing them through their digestive tract, the birds remove the pericarp and may also scarify the seeds, thus exposing them and improving conditions for germination. Additionally, titmice actively contribute to the dispersal of the plant in the landscape (Doroftei et al. 2005).

According to Đukić et al. (2010), the scarification of the pericarp has a positive effect on both the energy and intensity of germination, regardless of the NaCl content in the solution. On the other hand, they found that increased NaCl concentrations did not significantly affect the average germination time of fruits and scarified fruits. In our experiment, we observed not only a delay in the onset of germination for fruits (Fig. 2) but also a significant difference in the seedling

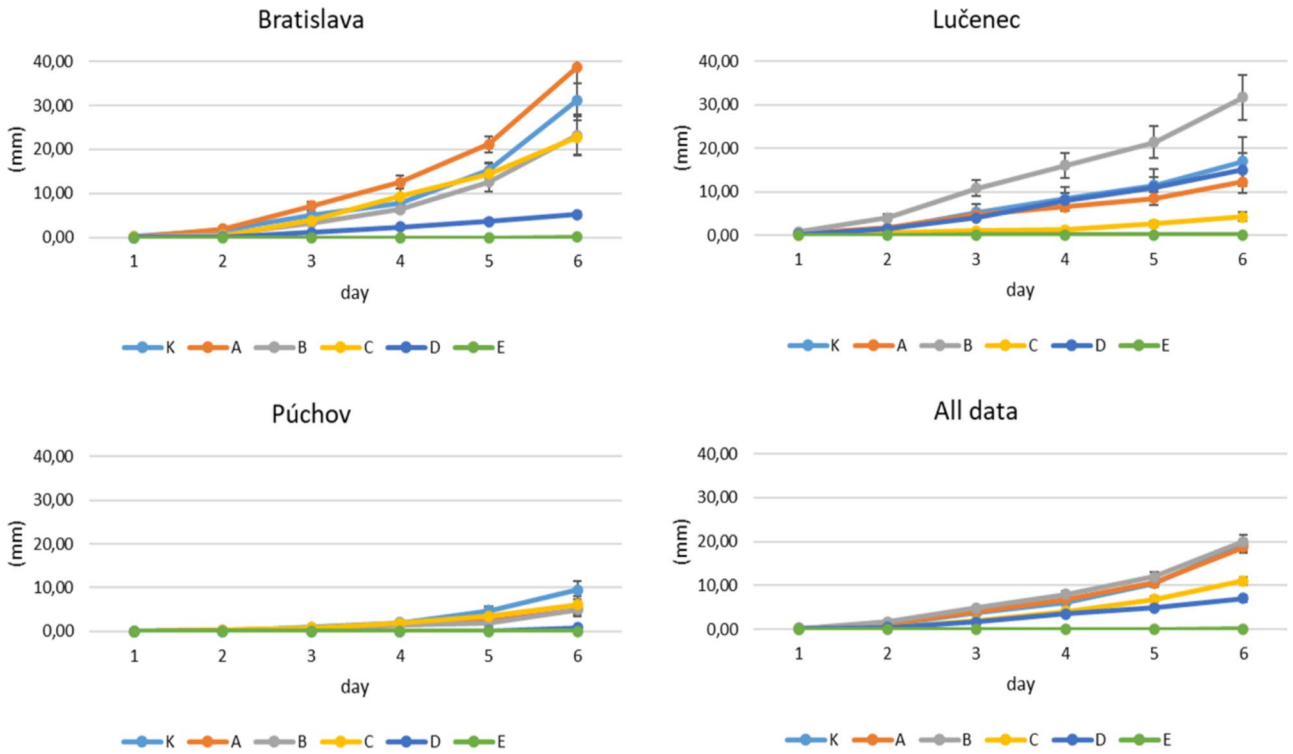


Fig. 5 Seedling vitality index I. of *A. fruticosa* (obtained from seeds) in relation to the salinity. NaCl solutions used: K 0%, A 0.12%, B 0.25%, C 0.50%, D 0.99%, and E 1.96%; mean and SE are given

length of germinating fruits and seeds (Tables 2–4). Additionally, when assessing data from all locations (All data), it was found that some NaCl solutions significantly reduced the value of the seedling vitality index I. in fruits (Table 4).

In addition to its tolerance to soil salinity, *A. fruticosa* also withstands drought (Yan et al. 2017; Cao et al. 2020; Jiang et al. 2025). Thus, it is a species capable of enduring both salt and water stress. This allows it to survive long-term on roadsides affected by chemical road maintenance applied during winter (Litalien and Zeeb 2020). This statement is supported by the results of a study on the species' distribution along roadsides and embankments of highways and expressways in Slovakia (Žarnovičan et al. 2024). The authors report that the highest frequency of the species was recorded on the oldest sections of these roads, i.e., on stretches long-term affected by salt from chemical winter maintenance. Due to these properties, *A. fruticosa* is a suitable tree species for afforestation of saline soils (Guo et al. 2018). It is also capable of improving their physical and chemical properties (Zhang 2014). The main prerequisites for successful afforestation of saline soils include selecting appropriate tree species resistant to high salt concentrations in the soils of the affected area. Zhang (2014) classifies *A. fruticosa* as a strong salinity-tolerant tree and recommends its use along with *Tamarix* sp. and *Lycium chinense* for planting in soils with salt content up to 0.5%. *A. fruticosa* is also used for the afforestation of areas degraded by mining activities (Seo et al. 2008; Chen et al 2023) and slopes of gullies and torrents (Untaru et al. 2003). For afforestation of soils threatened by water and wind erosion, Feng et al. (2015) recommend sowing *A. fruticosa* seeds in combination with herbs and grasses. Besides its soil protection function, the species has potential for use in energy production. The possibility of using *A. fruticosa* wood chips for energy purposes is highlighted by Krpan (2011, 2015) and Vaszkó (2023). However, when economically utilizing *A. fruticosa*, it is necessary to consider its invasive properties, its ability to invade various habitat types, and the legal regulations of the affected countries. It should be excluded from urban forestry and urban greening, especially in areas with natural riparian forests, where the species has optimal living conditions (Grabić et al. 2022). Nevertheless, the use of *A.*

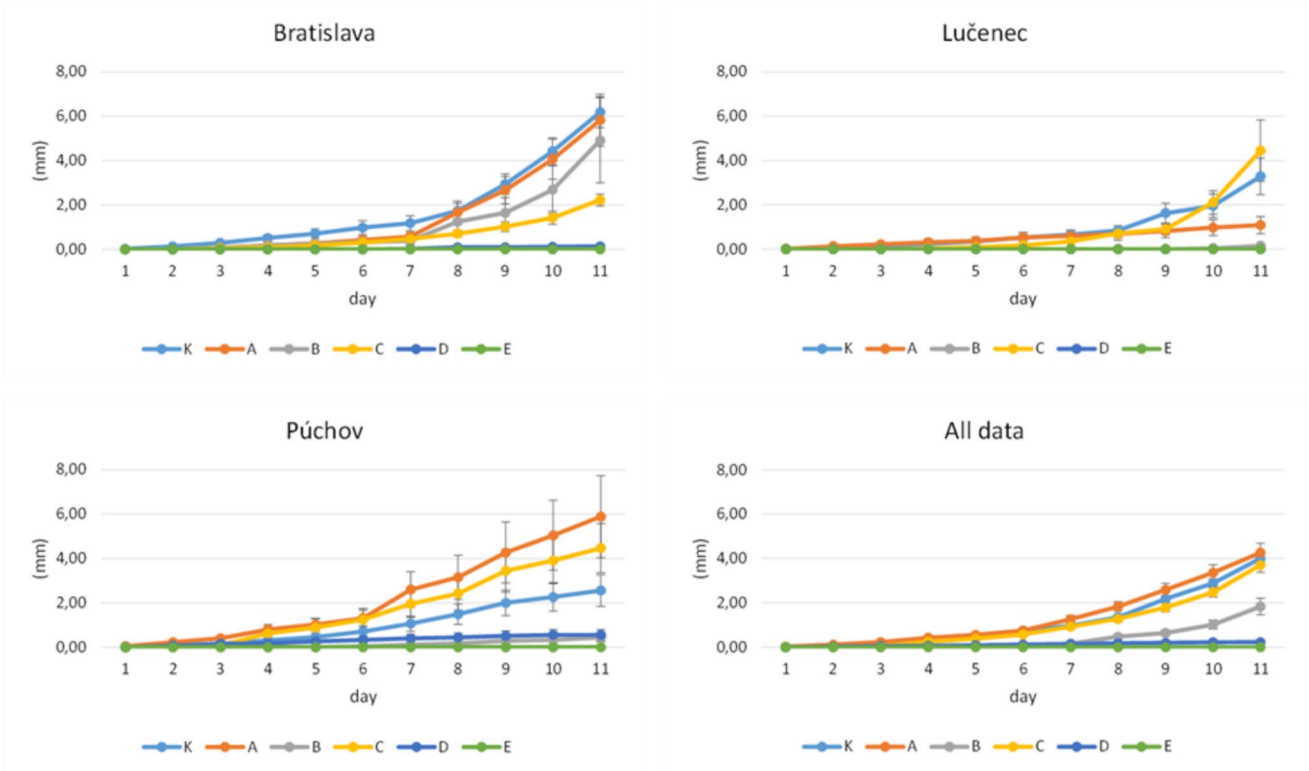


Fig. 6 Seedling vitality index I. of *A. fruticosa* (obtained from fruits) in relation to the salinity. NaCl solutions used: K 0%, A 0.12%, B 0.25%, C 0.50%, D 0.99%, and E 1.96%; mean and SE are given

fruticosa biomass for energy purposes would also contribute to the systematic removal of the species from invaded areas (Vaszkó 2023).

Conclusions

The study examined the effects of NaCl on the germination of *A. fruticosa* fruits (seeds with the pericarp) and seeds (seeds without the pericarp). The research confirmed that seeds germinate faster than fruits. The highest germination rates were observed in the control variants (without NaCl influence), but several samples of seeds and fruits showed increased germination in NaCl solutions with NaCl content up to 0.5%. Only the highest NaCl content (1.96%) was fatal for both seeds and fruits. It was found that seeds tolerate NaCl stress better than fruits. There was significant variability in responses to salinity, as fruits and seeds from different locations reacted differently to salinity. It can be concluded that the studied species, *A. fruticosa*, shows a tolerance to NaCl, making it suitable for afforestation of salt-contaminated soils in its native range. Moreover, due to its good tolerance not only to salt but also to water stress, this shrub would be probably suitable for semiarid environments. The results also contribute to understanding the long-term survival and reproduction of the species in habitats affected by secondary salinization.

Authors' contribution Conceptualization: Božena Šerá; formal analysis: Božena Šerá, Hubert Žarnovičan; investigation: Júlia Gatialová, Božena Šerá, Hubert Žarnovičan; methodology: Božena Šerá; writing and editing: Hubert Žarnovičan, Božena Šerá, Júlia Gatialová. All authors read and approved the final manuscript.

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Data Availability The data that support the findings are available upon request from the corresponding author.

Declarations

Research involving human participants and/or animals Not applicable.

Conflict of interest The authors declare that they have no conflict of interest.

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