Paulownia tomentosa (Thunb.) Steud. seed quality from different geographical locations in Ukraine

Article · November 2023

Андрій Петрович Іванюк
Ukrainian National Forestry University

Тарас Харачко
Ukrainian National Forestry University

Roman Lysiuk
Danylo Halytsky Lviv National Medical University

FORESTRY IDEAS, 2023, vol. 29, No 2 (66): 314–326

Paulownia tomentosa (Thunb.) Steud. seed quality from different geographical locations in Ukraine

Andrii Ivaniuk[1], Taras Kharachko[1], Roman Lysiuk[2*], Oleg Danchuk[1], and Oleksandr Cheban[1]

[1]Ukrainian National Forestry University, Lviv, Ukraine.
[2]Danylo Halytsky Lviv National Medical University, Lviv, Ukraine.
[*]E-mail: pharmacognosy.org.ua@ukr.net

Received: 13 September 2023 / Accepted: 23 November 2023 / Available online: 28 November 2023

Abstract

Biometric parameters of fruits and seeds of *Paulownia tomentosa* collected from trees growing in soil and climatic conditions of different geographical locations of Odesa, Zakarpattia (Mukachevo) and Lviv regions of Ukraine, as well as technical and absolute germination, germination energy, mean germination time and weight of 1000 seeds, were studied. The effect of different temperatures on seed germination in soil was evaluated under two temperature regimes. The influence of the duration of pre-soaking on seed germination was also determined. Pre-soaking of seeds in water and solutions of five different stimulants on germination in soil was also investigated. It has been found that in the conditions of Odesa region, the species formed larger fruits and the seeds were characterized by significant rate and uniformity of germination. Lowering of germination temperature caused a decrease in germination energy, laboratory and absolute seed germination, and increased the mean germination time of seeds. Pre-soaking of seeds increased significantly germination rate and its duration was associated with the parameters: germination energy, technical and absolute germination. Among the three seed collections, the highest technical germination was recorded for seeds from Lviv region. The seeds from Odesa region had the highest germination energy. The seeds were characterized by high germination rate in soil regardless of the geographical location of seed collection under the conditions of Ukraine. The highest germination in soil was found for seeds, collected in Lviv. Temperature during germination significantly affected the germination of seeds in soil. Under the temperature regime of 21 to 25 °C, soil fertility parameters were significantly higher. Pre-soaking of seeds had the highest stimulating effect on further germination of seeds in soil among the studied treatments. Pre-treatment of seeds with germination stimulants had generally a positive effect, increasing germination in soil.

Key words: biometric parameters, germination, pre-soaking, stimulators, temperature regimes, weight of 1000 seeds.

Introduction

Paulownia (*Paulownia tomentosa* (Thunb.) Steud.) is a fast-growing tree species native to China and East Asia (Bojnansky and Fargasova 2007, Bonner 2008, Icka et al. 2016). In Ukraine, the species is found in botanical gardens, rarely occurs in green areas of cities and in landscaping of private estates. Due to its unique characteristics, namely rapid growth, unassumingness to soil fertility and moisture, assimilation of significant amounts of carbon dioxide from the atmosphere, relative frost resistance and, most importantly, the ability to regenerate many times after cutting, the tree has been used in plantations for more than 40 years in different regions of America, Europe, Asia and Australia (Woods 2008, Akyildiz and Kol 2010, Hugo et al. 2013, Yadav et al. 2013, Icka et al. 2016). Paulownia is a promising source of plant material for possible development and further production of anti-inflammatory and antibacterial phytopharmaceuticals (Ivaniuk et al. 2023).

In recent years paulownia is under investigation also in Ukraine (Ivaniuk et al. 2023), being the promising tree for plantation cultivation with several short cutting rotation periods, as it is known that the speed of its growth and accumulation of biomass of the second and subsequent rotations of sapling origin is much higher than the first rotation. It can be explained by the ability of plants (of sapling origin) to feed and grow due to the well-developed root system of a felled tree (Zhu et al. 1986, Woods 2008, Akyildiz and Kol 2010, Yadav et al. 2013, Icka et al. 2016).

On the territory of modern Ukraine, *Paulownia tomentosa* appeared for the first time in the Nikitsky Botanical Garden in 1846. Later, the introduced tree has been successfully cultivated and acclimatized in the southern regions of Ukraine. Paulownia is currently widespread in various regions of Ukraine. The introduced tree grows successfully in Zakarpattia and Lviv regions (Kolesnikov 1974).

Many researchers have determined the sowing qualities of paulownia seeds or their explants (Kokhno et al. 1991, Jovanović et al. 2005, Bojnansky and Fargasova 2007, Bonner 2008, Mohamad et al. 2022, Poșta et al. 2022). Most of them note the high value of seed germination of the crop.

The influence of growth regulators on germination of seeds of different woody plant species has been described in several studies. According to Belelya (2014), pre-sowing seed treatment with a number of growth stimulants of various concentrations and for different time duration on European larch seeds can both increase germination energy and capacity and have a negative effect. Serediuk (2011) and Matsiakh et al. (2012) indicated the acceleration of the germination of spruce seeds under the action of growth stimulants. Taranenko (2011) and Hrechanyk et al. (2014) reported an increase in germination of Scots pine seeds under the influence of growth stimulants.

Todorović et al. (2005) revealed that light irradiation of paulownia seeds, which absorbed liquid smoke, cause the highest germination rate. Lazović et al. (2012) demonstrated the significant improvement of germination due to air plasma exposure of *P. tomentosa* seeds in the low pressure CCP reactor. Radu et al. (2015) reported that exposure for 20 min to homogeneous electric field accelerated the germination of paulownia seeds; the germination also depended on humidity and solar radiation intensity. Poșta et al. (2022) recently demonstrated that Nitrozyme, containing extract of sea kelp, had a slight effect on the germination rate of paulownia seeds. During the recent study of Prisa and Guerrini (2023), the positive effect of hydrogels on seed germination and seedling growth was shown. Turner et al. (1988) found that the germination of *P. tomentosa* seeds and the growth of its seedlings was affected by soil acidity. At pH 4.0, the seeds did not germinate. At pH 4.5, germination was very low and seedling growth was inhibited compared to seedlings, growing in soil at pH 5.5 and 6.5. Sabir and Hamad (2022) determined the optimal concentrations of NPK fertilizer and humic acid for paulownia seedling growth.

The purpose of the work was to investigate the sowing qualities of *P. tomentosa* seeds from different geographical locations of Ukraine and the influence of plant growth regulators and pre-soaking (in water) on seed germination. The results of this research could indicate the possibility of using seed zones for growing planting material and establishing plantations with biological resistance inherent in parent plants, in particular to the influence of low temperatures, soil and climatic conditions.

Materials and Methods

Determination of biometric parameters was carried out for paulownia fruits obtained from different geographical regions of Ukraine (Lviv 49.824227° N, 24.002693° E, Zakarpattia 48.620366° N, 22.292871° E and Odesa 46.485039° N, 30.742079° E). Harvesting of capsules was carried out in November 2022 by picking them from growing trees aged 26–35 years. During the measurement of biometric parameters, the research sample comprised the well-developed 200 boxes for each of three homogeneous batches of seeds. The length, diameter and weight of the generative organs (fruits) in the freshly harvested state were measured. Fruits' length and diameter were determined using an electronic callipers (accuracy up to 0.01 mm), and their weight – by electronic scale Axsis with a weighing accuracy of 0.001 g and a weight limit of 50 g. The diameter was determined at the maximum of the fruit width.

To determine the weight of 1000 seeds, technical and absolute germination, germination energy, mean germination time of *P. tomentosa* from harvested fruits, seeds have been obtained with further formation of three separate samples from the trees, grown in different locations of Ukraine. The seeds were obtained by processing the fruits in December 2022 and were stored in a dry, cool place (3 to 5 °C). All laboratory studies were carried out in January 2023 in the Laboratory of forest seeds at the Department of Forest Planting and Breeding of the Ukrainian National Forestry University.

The experimental part was conducted separately for samples from different geographical locations, in accordance with the current standards: determination of thousand-seed weight (DSTU 5036:2008 2009, ISTA 2011); germination capacity, germination energy, mean germination time (ISTA 2011, DSTU 8558:2015 2017).

To determine the effect of temperature on germination, seed germination was carried out under two temperature regimes: +15...20 °C and +21...25 °C (the minimum temperature at night, maximum – at daytime). Light intensity of 800 lux was applied at maximum temperatures (+20 °C and +25 °C) for 8 h.

Seed germination in soil was determined under indoor conditions (peat moss substrate, pH=6.9), in two temperature regimes: +15 °C at night and +20 °C during the day and +21 °C at night and +25 °C during the day; light intensity – 800 lux for 8 h. The seeds were laid out on the surface of the soil, and to avoid drying out, they were covered by a transparent polyethylene film. The experiment was performed four times for samples of different geographical regions.

In order to determine the influence of

stimulants on germination of seeds in soil, pre-sowing treatments of seeds with the following preparations were carried out:

- Stimovit (soaking in a 10% solution for 24 h);
- Kornevin (soaking in a 0.1% solution for 5 h);
- Succinic acid (soaking in a 0.1% solution for 24 h);
- Epin (2–3 drops per 100 ml of water and soaking for 4 h);
- Radifarm (soaking in a 0.25% solution for 24 h).

Data concerning the used pre-treatment regimes and the composition of preparations are presented in Table 1.

Table 1. Pre-treatment regimes and the composition of preparations.

Variant number	Commercial product or substance for seeds treatment	Active substance
1	Stimovit	Humic substances (HS) – up to 1.5 %, N – 1.4 %, P – 2 %, K – 1.5 %, Mg – 0.5 %, Mn – 50 mg·L^{-1}, Zn – 25 mg·L^{-1}, Cu – 50 mg·L^{-1}, Co – 5 mg·L^{-1}
2	Kornevin	4-(indol-3-yl)-butyric acid, 5 g·kg^{-1}
3	Succinic acid	Succinic acid
4	Epin	Epibrassinolide, 0.025 g·L^{-1}
5	Radifarm	Polysaccharides – 7 %; organic elements – 14 %; polypeptides – 11 %; steroidal glycosides – 0.2 %; amino acids (arginine, asparagine, betaine, tryptophan) – 1 %; complex of vitamins B1, B2, D, H, PP – 0.04 %; zinc (Zn) – 0.2 %; iron chelate (Fe) – 0.2 %
6 (control)	Without pre-soaking in water	-
7	Soaking in water for 24 h	Water
8	Soaking in water for 48 h	Water

Additionally, to determine the influence of the duration of seed soaking (in water) on germination parameters, the following treatments were tested:

• soaking the seeds with water (+20 °C) for 48 h;
• soaking the seeds with water (+20 °C) for 24 h;
• without pre-soaking (control).

Germination of seeds was recorded on the 3rd, 5th, 7th, 10th, and 14th days of observation. Germination energy was determined on the 7th day, and germination capacity – on the 14th day of the study (DSTU 8558:2015 2017).

Results and Discussion

The study of biometric parameters of fruits and seeds, collected from plants in different geographical regions, helped to reveal variability and to determine the dependence between the sizes of fruits, formed in regions with different soil and climatic conditions, and duration of the vegetative period. After the formation of seed samples, obtained from the harvested fruits of paulownia, the weight of 1000 seeds of different geographical locations was determined. Since the weight of 1000 paulownia seeds is up to 1 g, in order to determine this measure, according to DSTU 5036:2008 (2009), one sample of 500 seeds was counted and weighted with subsequent multiplication of their weight by 2. The measurements were carried out in quadruplicate (Table 2).

Table 2. Biometric parameters of fruits and seeds from three geographical locations in Ukraine.

Fruit diameter (width)			Fruit length			Weight of freshly harvested fruits			Weight of 1000 seeds		
X_m ±m_x (Limit), mm	***V*, %**	***P*, %**	**X_m ±m_x (Limit), mm**	***V*, %**	***P*, %**	**X_m ±m_x (Limit), g**	***V*, %**	***P*, %**	**X_m ±m_x (Limit), g**	***V*, %**	***P*, %**
Odesa city											
28.71 ±0.13 (24–32)	6.31	0.5	38.51 ±0.13 (34–41)	4.60	0.3	2.33 ±0.01 (2.1–2.5)	4.53	0.4	0.134 ±0.001 (0.132–0.138)	2.14	0.7
Mukachevo town											
27.75 ±0.15 (22–31)	7.76	0.5	37.6 ±0.11 (33–40)	4.19	0.3	1.76 ±0.01 (1.5–2.1)	8.22	0.6	0.123 ±0.001 (0.120–0.125)	1.69	0.8
Lviv city											
23.44 ±0.3 (15–27)	18.34	1.3	34.15 ±0.34 (21–38)	14.11	1.0	1.44 ±0.02 (0.8–1.7)	22.54	1.4	0.107 ±0.002 (0.110–0.107)	4.21	1.9

Note: X_m – average arithmetic value; m_x – error of the average value; *V* – coefficient of variation, %; Limit – minimum and maximum values; *P* – accuracy of the experiment, %.

Analysis of data, presented in Table 2, shows the homogeneity of the samples of the investigated characteristics. It is worth mentioning that the fruits, collected in Odesa and Mukachevo, have a slight variation in all studied parameters. In fruits, harvested in Lviv, we observed an average variation in their size and a significant variation in weight. In our opinion, this is due to the less favourable climatic conditions for the formation and growth of fruits of paulownia, growing in Lviv. It is worth noting that, according to all average indicators, one can observe the increase of the determined values of the fruit samples, obtained from Odesa, compared to the samples, collected in Lviv. Among the three studied locations, the length of the fruits changes the least, and their weight varied the most. The analysis of data on the weight of 1000 seeds indicated a decrease in the weight of seeds in plants, growing in a region with a shorter vegetation period (Lviv). It is advisable to take into account the seed weight parameters, determined by us, when specifying in nurseries the norms for sowing seeds, collected in different geographical locations. There is information in the literature that the weight of 1000 seeds varies from 0.14 to 0.25 g (Milev et al. 2004), on average – 0.17 g (Bonner 1990, Pasiecznik 2008). Our results for three samples are slightly below the lower limit, therefore, the analysed seeds are relatively small.

Under the temperature regime of +20...25 °C, the technical germination of paulownia seeds was determined, which varies from 88 to 99 % and was slightly higher than the value given in literature (Kokhno et al. 1991), regardless of their geographical locations (Table 3). Moreover, the highest value of the germination index in all variants of the study was found for seeds from Lviv region, which exceeded by 6–7 % appropriate indicators of seeds from Odesa and Mukachevo.

Table 3. Indicators of seed germination under the temperature regime of +21...25 °C.

Germination indicators		Locations where seeds were collected								
		Odesa city			Mukachevo town			Lviv city		
		Duration of soaking in water before sowing seeds for germination, h								
		48	24	0	48	24	0	48	24	0
Germination energy, %	X_m	85.0	82.8	75.3	34.0	16.0	7.8	50.8	37.8	11.0
	m_x	1.4	0.9	0.9	0.4	0.7	0.3	1.3	0.9	0.4
	V	3.33	2.06	2.27	2.40	8.84	6.45	4.93	4.52	7.42
	P	1.66	1.03	1.13	1.20	4.42	3.23	2.46	2.26	3.71
Technical germination, %	X_m	93.0	90.0	89.0	93.0	90.8	87.8	98.8	96.8	94.8
	m_x	1.5	1.9	0.8	1.5	1.3	1.5	0.6	1.0	0.9
	V	3.17	4.16	1.83	3.17	2.75	3.53	1.27	2.13	1.80
	P	1.58	2.08	0.92	1.58	1.38	1.76	0.64	1.07	0.90
Absolute germination, %	X_m	94.5	90.0	89.8	93.0	91.8	89.3	99.3	97.0	96.0
	m_x	0.9	1.2	1.2	0.4	0.9	1.2	0.3	0.7	0.4
	V	1.83	2.72	2.63	0.88	2.06	2.65	0.50	1.46	0.85
	P	0.92	1.36	1.32	0.44	1.03	1.32	0.25	0.73	0.43
Mean germination time, days		6.4	6.4	7.3	9.1	10.4	10.7	8.3	8.9	10.1

Note: X_m – average arithmetic value; m_x – error of the average value; V – coefficient of variation, %; P – accuracy of the experiment, %.

Pre-soaking, the duration of which correlates with indicators of technical germination, had a significant effect on seed germination. Other authors also indicated in their studies the positive effect of seed soaking on the acceleration of germination. Houšková et al. (2021) investigated the effect of pre-soaking in water on germination energy, mean germination time and germination capacity of Scots pine and Norway spruce seeds and recommended the method of pre-treatment of seeds to increase germination energy. Germination of paulownia seed can reach 75–90 % even after one year of storage; the germination process can be accelerated by soaking the seeds in warm water for 10 min and then sowing under conditions of intense light and high temperature (Zhu et al. 1986).

During soaking of seeds in water for 48 h, an increase in germination by 4–5 % was observed, in the case of soaking for 24 h – by 1–3 %, compared to the control (without soaking). Pre-soaking had even greater effect on the rate of seed germination. Thus, the energy of seed germination increased by 10–40 % and by 8–27 % (depending on the geographic location) after pre-soaking for 48 h and 24 h, respectively. In general, paulownia seeds, collected in southern region of Ukraine (Odesa), were characterized by the highest germination speed; 84.3–92.3 % of all germinated seeds germinated during seven days of observation. Only the seeds from Odesa developed healthy, normally developed roots already on the third day of observation. To our opinion, there is a correlation between the speed of germination and the weight of the seed, because heavier seeds (in particular, collected in the city of Odesa) have a greater supply of nutrients and are capable for faster growth and development of the embryo.

The mean germination time also characterizes the rate of seed germination. For seeds collected in Odesa, the mean germination time was the lowest, ranging from 6.4 to 7.3 days, which indicated a very high rate of seed germination. Seeds from Mukachevo were characterized by the lowest germination rate (from 9.1 to 10.7 days), which is 1.4 times longer than for those from Odesa. The germination rate of the seeds, collected in Lviv, occupied an intermediate position among the three investigated locations of their harvesting.

Examining ungerminated seeds on the 14th day of observation revealed empty (8.3–20.0 % of the total number of ungerminated seeds), rotten (20.0–36.4 %) and healthy seeds (54.5–100 %), which made possible to determine the absolute germination. Insignificant amount of empty seeds does not have a significant effect on the parameter of absolute germination. In four out of nine variants of the study, the absolute germination did not differ from the technical germination, in the remaining variants it exceeded the technical germination by only 1 %.

Our results of investigation, concerning the effect of temperature on seed germination, confirm the research outcomes of other scientists. Grubišicá and Konjević (1992) pointed out the positive effect of changing the temperature regime and the impact of light on the germination of paulownia seeds. Barton et al. (2007) claimed that storing of paulownia seeds for 4–6 weeks in moist peat or sand at a temperature of about 5 °C had an effective impact on its germination.

In production conditions, it is quite difficult to maintain a temperature regime above +20 °C in the cold season. The study on the influence of temperature reduction on seed germination was carried out at a temperature regime of +15...20 °C, which corresponds to the temperature regime of greenhouses (at the beginning of spring) and production premises, in which preliminary testing of sowing qualities of the seeds is carried out (Table 4).

In general, a decrease in the germination temperature of the seeds of paulownia lead to a reduction in all indicators of germination. Thus, the technical germination of the seeds varies in the range 66–79 %, which was lower than the indicators described in the literature (Kokhno et al. 1991). Compared to germination at a temperature of +20...25 °C, the decrease of the studied indicator is 20–23 %, depending on the variants of the experiment. The highest value of technical germination was found for seeds from Lviv (73–79 %), the lowest one – in seeds from Mukachevo (66–70 %), which corresponds to the results of previous studies.

Pre-soaking of the seeds at lower temperatures also had a positive effect on seed germination. The increase in the technical germination index, depending on the location of collection, was 4–7 % (48 h of soaking) and 2–3 % (24 h), compared to the control.

It has been found that the temperature regime of +15...20 °C significantly

Table 4. Indicators of seed germination under the temperature regime of +15...20 °C.

Germination indicators		Locations where seeds were collected								
		Odesa city			Mukachevo town			Lviv city		
		Duration of soaking in water before planting seeds for germination, h								
		48	24	0	48	24	0	48	24	0
Germination energy, %	X_m	7.3	5.0	0	0	0	0	0	0	0
	m_x	0.3	0.4	-	-	-	-	-	-	-
	V	6.90	16.33	-	-	-	-	-	-	-
	P	3.45	8.16	-	-	-	-	-	-	-
Technical germination, %	X_m	73.3	69.3	65.8	69.8	67.8	66.0	78.8	74.8	73.0
	m_x	0.9	0.9	0.9	0.9	1.0	0.8	0.9	0.9	0.4
	V	2.33	2.47	2.60	2.45	3.04	2.47	2.17	2.28	1.12
	P	1.17	1.23	1.30	1.22	1.52	1.24	1.08	1.14	0.56
Absolute germination, %	X_m	74.0	70.0	66.3	70.8	68.5	67.5	80.3	76.0	74.3
	m_x	0.7	0.8	0.9	0.9	1.3	1.0	0.9	0.8	0.6
	V	1.91	2.33	2.58	2.68	3.86	3.08	2.13	2.15	1.69
	P	0.96	1.17	1.29	1.34	1.93	1.54	1.06	1.07	0.85
Mean germination time, days		12.6	12.6	13.9	13.9	14.0	14.2	14.3	14.4	14.5

Note: X_m – average arithmetic value; m_x – error of the average value; V – coefficient of variation, %; P – accuracy of the experiment, %.

slows down the process of seed germination. Germination energy was equal to 0 % in seven out of nine variants of the experiment. Only seeds from southern location (Odesa) were characterized by germination energy of 5 % and 7 % after pre-soaking for 24 and 48 h, respectively. The duration of the mean germination time increased significantly (12.6–14.5 days), which is 1.3–2.0 times more than the same variants of the experiment at a temperature of +20...25 °C.

When determining seed germination in soil, the count of germinated seeds was performed on the 14th day of observation. Under the temperature regime of +21...25 °C, the value of the seed germination in soil varied from 83.8 ±1.31 % to 99.8 ±0.25 % (Table 5). Moreover, in the control (seeds without treatment with a stimulator of germination), the lowest germination in soil was characteristic for seeds, collected in Odesa (83.8 ±1.31 %), the highest one – for seeds from Lviv (92.0 ±0.82 %).

Pre-soaking of seeds resulted in an increase of seed germination in soil compared to the control by 0.6–13.1 %. Moreover, pre-soaking for 24 h was more effective, which led to an increase in germination by 6.0–13.1 %. With pre-soaking for 48 h, the indicators of seed germination in soil were slightly lower and exceed those of the control by 0.6–4.7 %.

The use of the stimulators of seed germination under the temperature regime of +21...25 °C confirms their effectiveness. In general, with their application, an increase of indicators of seed germination in soil was recorded at the level of 3.2–10.1 % compared to the control for seeds from all studied locations. The highest result was found for Stimovit (exceeding by

Table 5. Indicators of seed germination in soil under the temperature regime of +21...25 °C.

Regulators of seed germination	Germination in soil of the seeds, collected from different locations								
	Odesa city			Mukachevo town			Lviv city		
	$X_m \pm m_x$, %	*V*, %	*P*, %	$X_m \pm m_x$, %	*V*, %	*P*, %	$X_m \pm m_x$, %	*V*, %	*P*, %
Stimovit	92.3 ±0.63	1.36	0.68	95.8 ±0.48	1.00	0.50	99.3 ±0.48	0.96	0.48
Kornevin	92.0 ±0.41	0.89	0.44	92.0 ±1.47	3.20	1.60	99.5 ±0.29	0.58	0.29
Succinic acid	88.3 ±0.63	1.43	0.71	90.3 ±0.85	2.13	1.06	95.8 ±0.85	1.78	0.89
Epin	87.8 ±0.85	1.95	0.97	95.5 ±0.65	1.35	0.68	99.8 ±0.25	0.50	0.25
Radifarm	87.8 ±0.25	0.57	0.28	96.3 ±0.85	1.77	0.89	95.5 ±0.65	1.35	0.68
No soaking (control)	83.8 ±1.31	3.14	1.57	87.5 ±0.65	1.48	0.74	92.0 ±0.82	1.77	0.89
Soaking for 24 h	92.3 ±0.85	1.85	0.93	99.0 ±0.41	0.82	0.41	97.5 ±0.65	1.35	0.68
Soaking for 48 h	87.5 ±1.04	2.38	1.19	88.0 ±0.41	0.97	0.49	96.3 ±0.85	1.77	0.89

Note: X_m – average arithmetic value; m_x – error of the average value; *V* – coefficient of variation, %; *P* – accuracy of the experiment, %.

7.9–10.1 %), the lowest indicators of seed germination in soil were recorded after pre-treatment of seeds with succinic acid (exceeding by 4.1–5.8 %).

It has been established that at a temperature of +15...20 °C, the process of germination of the paulownia seeds was significantly slowed down; the seed germination in soil is lower, compared to the higher temperature regime, and the values of its indicators vary from 69.8 ±0.48 % to 95.0 ±0.41 %, which was less by 1.5–23.0 % than for the same variants of the experiment at temperature of +21...25 °C (Table 6).

A comparative assessment of the germination in soil for paulownia seeds from different geographical locations under the temperature regime +15...20 °C confirms

Table 6. Indicators of seed germination in soil under the temperature regime of +15...20 °C.

Regulators of seed germination	Germination in soil of the seeds, collected in different locations								
	Odesa city			Mukachevo town			Lviv city		
	$X_m \pm m_x$, %	*V*, %	*P*, %	$X_m \pm m_x$, %	*V*, %	*P*, %	$X_m \pm m_x$, %	*V*, %	*P*, %
Stimovit	73.3 ±0.85	2.33	1.17	76.5 ±0.65	1.69	0.84	95.0 ±0.41	0.86	0.43
Kornevin	72.5 ±0.65	2.07	1.03	72.7 ±0.85	2.62	1.31	94.8 ±0.85	1.80	0.90
Succinic acid	82.8 ±0.85	2.06	1.03	73.8 ±0.85	2.45	1.22	93.5 ±1.04	3.28	1.64
Epin	80.5 ±1.55	3.86	1.93	79.5 ±1.04	2.62	1.31	94.8 ±1.25	2.64	1.32
Radifarm	78.0 ±1.08	2.77	1.38	74.8 ±0.85	2.28	1.14	93.0 ±0.71	1.52	0.76
No soaking (control)	69.8 ±0.48	1.20	0.60	72.3 ±0.63	1.61	0.80	91.8 ±0.63	1.37	0.69
Soaking for 24 h	73.0 ±0.41	1.12	0.56	76.0 ±1.63	4.30	2.15	94.0 ±1.08	2.30	1.15
Soaking for 48 h	74.8 ±1.55	4.14	2.07	79.8 ±1.44	3.60	1.80	94.8 ±0.85	1.80	0.90

Note: X_m – average arithmetic value; m_x – error of the average value; *V* – coefficient of variation, %; *P* – accuracy of the experiment, %.

the highest germination rate for seeds from Lviv (from 91.8 ±0.63 % to 95.0 ±0.41 %). The values of the parameters of germination in soil for seeds of two other origins did not differ significantly from each other, but were significantly lower than the indicators of germination for seeds from Lviv.

Pre-soaking of seeds at a lower temperature regime of germination also had a positive effect on germination in soil, which increased compared to the control by 2.4–5.1 % when soaked for 24 h and by 3.3–10.4 % if soaked for 48 h. Comparing the experiment at a temperature of +21...25 °C, longer pre-soaking of seeds in water with a temperature of 20 °C (48 h versus 24 h) had more effective impact on soil germination. Toour opinion, in this case, the determining factor was the temperature, which contributed to the activation of the process of seed germination.

The use of stimulators at temperatures of +15...20 °C increased germination in soil by 3.9–18.6 % compared to the control in seeds originating from Odesa, by 0.6–10.0 % – from Mukachevo and by 1.3–3.5 % for seeds from Lviv.

A generalized assessment for the effect of stimulators on germination in soil of the seeds made it possible to reveal their effectiveness under both temperature regimes: +15...20 °C and +21...25 °C (Fig. 1).

The temperature of seed germination significantly affected germination in soil (see Fig. 1). Parameters of the seed germination in soil under the temperature regime of +21...25 °C exceeded those at a lower temperature in all variants of the experiment.

In general, under the germination temperature regime of +21...25 °C, the maximum value of the indicator of germination in soil – 95.8 % was recorded in the case of the use of Stimovit, the minimum one (91.5 %) – of Succinic acid.

Under the germination temperature regime of +16...20 °C, the ranking of preparations in order of decreasing their effect on seed germination in soil differs from the previous one and was as follows: Epin, Succinic acid, Radifarm, Stimovit, Kornevin.

Generalized parameters of the germination of paulownia seeds in soil, depending on the geographical origin, are shown in Figure 2.

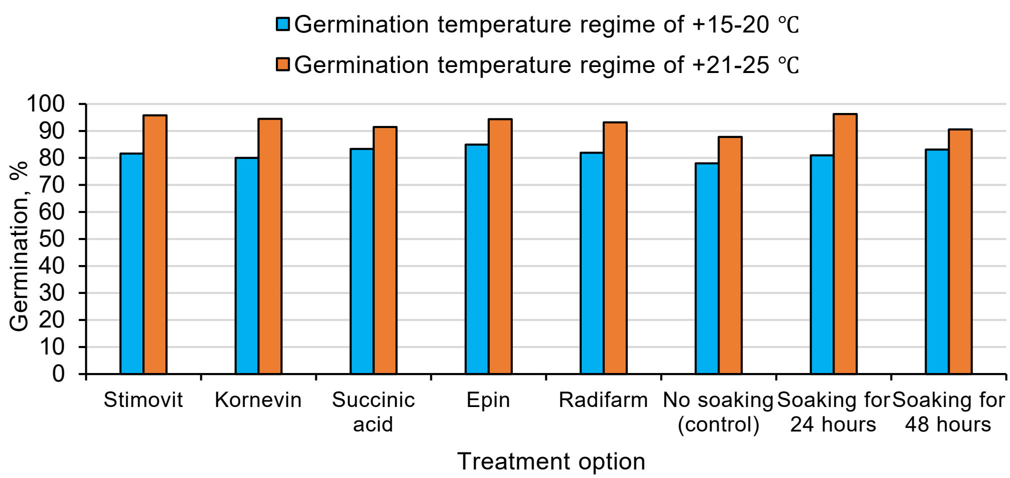

Fig. 1. The effect of germination stimulants on the germination in soil.

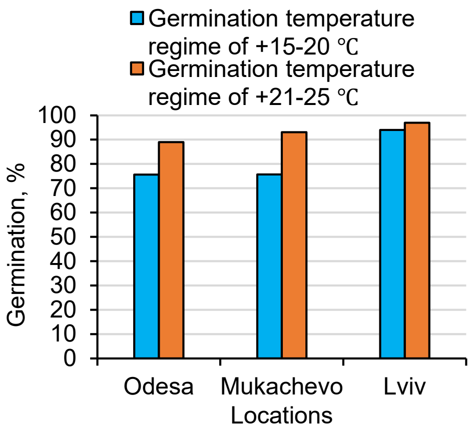

Fig. 2. The influence of the geographical locations, where the seeds collected, on the germination in soil.

According to Figure 2, seeds collected in Lviv were characterized by the highest germination in soil, regardless of the temperature regime of germination. Indicators of germination in soil of seeds from Mukachevo and Odesa were lower, respectively by 3.9–8.3 % and 8.0–8.4 %, depending on the germination temperature. After conducting an additional accounting of germinated seeds on the 28th day after sowing, it was found that the parameters of germination in soil did not change. It demonstrated the ability of seeds to germinate within two weeks after sowing them on the surface of the soil under the two studied temperature regimes.

Conclusions

Under the conditions of the southern regions of Ukraine, paulownia forms larger fruits, the weight of which exceeded the weight of fruits from Zakarpattia and Lviv regions by 24 and 38 %, accordingly. Seeds from Odesa were heavier and characterized by higher germination rate and germination energy.

Paulownia seeds are characterized by high technical germination regardless of geographical location.

To increase the rate of seed germination and germination energy, it is advisable to adhere to a temperature regime +20...25 °C. Decrease in temperature causes decrease in germination. The mean germination time was 1.3–2.0 times higher at temperatures of +15...20 °C.

Pre-soaking of seeds significantly affected germination indicators: both technical and absolute germination, as well as the rate of seed germination increased, and the mean germination time decreased. Increase in the duration of soaking (from 24 to 48 h) correlated with enhancement of technical germination and energy of seed germination.

Seeds of paulownia were characterized by high germination in soil regardless of the geographical location of parent trees under the conditions of Ukraine; ~~the~~ highest germination in soil was characteristic for the seeds from Lviv.

Temperature of germination had a significant effect on seed germination in soil. Under germination temperature regime of +21...25 °C, parameters of germination in soil were significantly higher.

Pre-soaking of seeds has the highest stimulatory effect on further germination of seeds in the soil among the investigated germination stimulants. Pre-treatment of seeds with Stimovit, Kornevin, Succinic acid, Epin, Radifarm generally had a positive effect, increasing germination in soil. The items related to the feasibility of using stimulators of germination and growth of plants, requires further study to investigate the complex effect of a specific preparation on both germination and juvenile development of seedlings.

In general, the studied seeds, collected from three geographical locations in Ukraine, were characterized by high sowing qualities, can be used for growing planting material with further application in plantation forestry.

References

Akyildiz M.H., Kol H.S. 2010. Some technological properties and uses of paulownia (*Paulownia tomentosa* Steud.) wood. Journal of Environmental Biology 31(3): 351–355.

Belelya S. 2014. Effect of growth stimulants on European larch seeds germination. Proceedings of the Forestry Academy of Sciences of Ukraine 12: 91–98 (in Ukrainian).

Barton I.L., Nicholas I.D., Ecroyd C.E. 2007. *Paulownia*. Forest Research Bulletin. No 231. Sustainable Farming Fund. 71 p.

Bojnansky V., Fargasova A. 2007. Atlas of seeds and fruits of central and east-European flora: The Carpathian Mountains Region. Springer. 1046 p.

Bonner F.T. 1990. *Paulownia tomentosa* (Thunb.) Sieb. & Zucc. ex Steud. Royal paulownia. In: Burns R.M., Honkala B.H., technical coordinators. Silvics of North America, vol. 2, Hardwoods. Agriculture Handbook 654. Washington, DC, U.S. Department of Agriculture, Forest Service: 501–502.

Bonner F.T. 2008. *Paulownia tomentosa* (Thunb.) Sieb. & Zucc. ex Steud. royal paulownia. In: Bonner F.T., Karrfalt R.P. (Eds), The Woody Plant Seed Manual. Washington (DC), USDA Forest Service Agriculture Handbook 727: 772–773.

DSTU 5036:2008 2009. National standard of Ukraine: Seeds of trees and shrubs. Methods of selection of tests, determination of purity, thousand-seed weight and moisture. Kyiv, Derzhspozhyvstandart Ukrainy. 45 p. (In Ukrainian).

DSTU 8558:2015 2017. National standard of Ukraine: Seeds of trees and shrubs. Methods for seed testing (germination, viability, benign). Kyiv, Derzhspozhyvstandart Ukrainy. 91 p. (in Ukrainian).

Grubišicá D., Konjević R. 1992. Light and temperature action in germination of seeds of the empress tree (*Paulownia tomentosa*). Physiologia Plantarum 86(3): 479–483. https://doi.org/10.1111/j.1399-3054.1992.tb01347.x

Houšková K., Klepárník J., Mauer O. 2021. How to accelerate the germination of Scots pine and Norway spruce seeds? Journal of Forest Science 67(3): 134–142. https://doi.org/10.17221/133/2020-JFS

Hrechanyk R.M., Hula L.O., Hbur V.O. 2014. The Effect of Growth Regulators on Scotch Pine (*Pinus sylvestris* L.) Seeds Germination. Scientific Bulletin of UNFU 24(9): 60–64 (in Ukrainian).

Hugo D.Z.V., Bocanegra J.A.J., Torres F.P., Pleguezuelo C.R.R., Martíne J.R.F. 2013. Biomass Yield Potential of Paulownia Trees in a Semi-Arid Mediterranean Environment (S Spain). International Journal of Renewable Energy Research 3(4): 789–793.

Icka P., Damo R., Icka E. 2016. *Paulownia tomentosa*, a Fast Growing Timber. Annals of 'Valahia' University of Targoviste – Agriculture 10(1): 14–19. doi: 10.1515/agr-2016-0003

ISTA 2011. International Rules for Seed Testing. Zurich, International Seed Testing Association. 276 p.

Ivaniuk A., Zayachuk V., Lysiuk R., Kharachko T., Lisoviy M. 2023. Physical and mechanical properties of *Paulownia tomentosa* (Thunb.) Steud. wood under the conditions of the Western Forest-Steppe of Ukraine. Forestry Ideas 29(1): 168–180.

Jovanović V., Giba Z., Djoković D., Milosavljević S., Grubisić D., Konjević R. 2005. Gibberellic acid nitrite stimulates germination of two species of light-requiring seeds via the nitric oxide pathway. Annimals of the New York Academy of Science 1048(1): 476–481. https://doi.org/10.1196/annals.1342.070

Kokhno I.A., Kurdiuk A.M., Dudyk N.M., Kokhno N.A. (Ed.) 1991. Fruits and seeds of trees and bushes, cultivated in Ukrainian SSR. Kyiv, Naukova dumka Publisher.

320 p. (in Russian).

Kolesnikov A.I. 1974. Decorative dendrology. Moscow: Lesnaia promyshlennost. 704 p. (in Russian).

Lazović S., Puač N., Maletić D., Živković S., Giba Z., Cvelbar U., Mozetic M., Kovac J., Filipic T., Malovic G., Petrović Z.L. 2012. Treatment of *Paulownia tomentosa* seeds in the low pressure CCP reactor. 4th International conference on plasma medicine, Orléans-France: 207.

Matsiakh I.P., Kramarets V.O., Gut R.T. 2012. The influence of growth stimulants of seed germination of spruce. Scientific Bulletin of UNFU 22(5): 34–38 (in Ukrainian).

Milev M, Aleksandrov P., Petkova K., Iliev N. 2004. *Paulownia tomentosa* (Thunb.) Sieb. & Zuec. In: Sowing materials from broad-leaved species. Videnov & Son Ltd., Sofia: 222–223 (in Bulgarian).

Mohamad M.E., Awad A.A., Majrashi A., Esadek O.A.A., El-Saadony M.T., Saad A.M., Gendy A.S. 2022. *In vitro* study on the effect of cytokines and auxins addition to growth medium on the micropropagation and rooting of *Paulownia* species (*Paulownia hybrid* and *Paulownia tomentosa*). Saudi Journal of Biological Sciences 29(3): 1598–1603. https://doi.org/10.1016/j.sjbs.2021.11.003

Pasiecznik N. 2008. *Paulownia tomentosa* (Paulownia). CABI Compendium. https://doi.org/10.1079/cabicompendium.39100

Poșta D.S., Rózsa S., Gocan T.-M., Cântar I.-C. 2022. Research on seed germination stimulation at *Paulownia tomentosa* Thunb. Steud. Current Trends in Natural Sciences 11(22): 231–239. https://doi.org/10.47068/ctns.2022.v11i22.027

Prisa D., Guerrini G. 2023. Innovative hydrogels use in the germination and growth of tree species *Paulownia tomentosa* and *Cupressus sempervirens*. GSC Advanced Research and Reviews 14(2): 121–128. https://doi.org/10.30574/gscarr.2023.14.2.0058

Radu A., Criveanu H.R., Inoan S.L. 2015. The Influence of the Electric Field on the Seed Germination Process for *Paulownia tomentosa* (Thunb.) Stend. Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Horticulture 72(1): 170–175. https://doi.org/10.15835/buasvmcn-hort:10972

Sabir N.A., Hamad S.O. 2022. Effect of Chemical Fertilizer and Humic Acid on the Growth and Development of *Paulownia tomentosa* Seedlings. Zanco Journal of Pure and Applied Sciences 34(4): 11–32. http://dx.doi.org/10.21271/ZJPAS.34.4.3

Serediuk O.O. 2011. Influence of plant growth and development regulators on *Picea abies* (L) H. Karst seed germination. Bulletin of the National University of Bioresources and Natural Resources of Ukraine (Kyiv) 164(3): 200–205 (in Ukrainian).

Taranenko Yu.M. 2011. Influence of plant growth regulators on seed quality of *Pinus sylvestris* L. Bulletin of the National University of Bioresources and Natural Resources of Ukraine (Kyiv) 164(3): 213–220 (in Ukrainian).

Todorović S., Giba Z., Živković S., Grubišić D., Konjević R. 2005. Stimulation of Empress Tree Seed Germination by Liquid Smoke. Plant Growth Regulation 47: 141–148. https://doi.org/10.1007/s10725-005-3253-z

Turner G.D., Lau R.R., Young D.R. 1988. Effect of acidity on germination and seedling growth of *Paulownia tomentosa*. Journal of Applied Ecology 25(2): 561–567. https://doi.org/10.2307/2403844

Woods V.B. 2008. *Paulownia* as a novel biomass crop for Northern Ireland? Agri-Food and Bioscience Institute, Occasional publication No. 7. 47 p.

Yadav N., Vaidya B., Henderson K., Lee J., Stewart W., Dhekney S., Joshee N. 2013. A Review of *Paulownia* Biotechnology: A Short Rotation, Fast Growing Multipurpose Bioenergy Tree. American Journal of Plant Sciences 4(11): 2070–2082. http://dx.doi.org/10.4236/ajps.2013.411259

Zhu Z.-H., Chao C.-Ju, Lu X.-Yu, Gao X.Y. 1986. Paulownia in China: cultivation and utilization by Chinese Academy of Forestry Staff. Asian network for biological sciences and international development research centre, Beijing. 65 p.