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FROST RESISTANCE OF THE INTRODUCED SPECIES OF TREES IN THE URBANIZED ENVIRONMENT (LUTSK CITY, UKRAINE)

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Abstract

The results of determining the frost resistance of nine introduced species of woody plants in an urbanized environment (on the example of Lutsk city) are presented. The effect of low temperatures on woody plants has been experimentally determined. The degree of damage to the tissues of shoots (bark, cambium, wood, core, buds) by direct freezing using a system of coefficients was studied. The basic patterns of tissue damage are established, taking into account their physiological inequality in vital activity and regenerative capacity of plants. A comparative analysis of the assessment of damage to introduced species depending on the freezing temperature is presented.

Key words*: frost resistance, introducers, urbanized environment, degree of damage.*

INTRODUCTION

The resistance to various environmental factors is a necessary condition for the successful growth and development of introduced tree species. Freezing, winter drying, sunburn, etc., are the most vulnerable factors of the winter period, which sometimes cause harmful damage to plants (Vasiliev, 1966). From the very beginning, there is a problem of determining the frost and winter hardiness of introducers, in other words suitability for growing in areas with unfavorable winter conditions or for introduction from regions with more temperate climate. Winter hardiness of plants characterizes their endurance to a complex of dangerous factors of the environment during overwintering. Taking into account the full range of stress conditions that a plant may experience in the cold season, winter hardiness is a complex characteristic where the freezing temperature is the most significant stressor (Sakai, 1973).

Frost is the main meteorological factor influencing silvicultural reclamation in temperate climates (Snyder et al., 2005). Freezing threatens the integrity of plants, stimulating the growth of ice crystals in plant tissues. Complete or partial damage to plants due to low temperatures is most often caused by water freezing in the cells and is accompanied by dehydration and osmotic shock. Ice formation in the intercellular spaces can cause mechanical injury to cell walls and membranes (Musiienko, 2001).

Frost resistance of plants is a genetically determined trait that is controlled by many genes, and laboratory testing at low temperatures makes it possible to determine the potential resistance of plants at the tissue level. Frost resistance is understood as the ability of plants to tolerate long winter frosts without harm (Krasavtsev, 1960; Potanin et al., 2005). Many plant species with temperate and cold climates can increase their ability to withstand low temperatures depending on environmental conditions (Ambroise et al., 2020). This complex process, called acclimatization or hardening, involves biochemical and physiological changes (Parker, 1960). At a certain range of negative temperatures, woody plants can increase their frost resistance

(Krasavtsev, 1967). The process of increase of frost resistance of woody plants after entering the state of calmness was called the first process of the hardening stage by Tumanov (1979).

However, winters with critically low temperatures in Ukraine are observed every 10-14 years. Therefore, plants are tested at low temperatures in the laboratory (Potanin et al., 2005) to determine the potential for frost resistance.

Taking in account that the species of dendrodiversity of modern urban areas are represented by both aboriginal and introduced species, laboratory analysis of frost resistance of the latter is necessary to determine the success of their cultivation in the study area (Kokhno, 2002).

The purpose of the research is to determine the potential resistance of introduced woody plant species to the effects of low temperatures in the urbanized environment of the Lutsk city, to determine the degree of damage to the tissues of the shoots depending on the freezing temperature.

MATERIALS AND METHODS

We selected introduced taxons for determination of frost resistance. These taxons aren't common in urban landscaping, but are perspective in the conditions of Lutsk (Kovalevskiy & Shepelyuk, 2016). To be exact: *Aesculus* × *carnea* Zeyh., *Rhus typhina* L., *Gleditsia triacanthos* L., *Acer platanoides* 'Globosum', *Cercidiphyllum japonicum* Sieb. Et Zucc., *Phellodendron amurense* Rupr., *Catalpa hybrida* Spath., *Magnolia* × *soulangeana* Soul.-Bod., *Liriodendron tulipifera* L.

The study of frost resistance of plants was carried out by the method of direct freezing of shoots in the laboratory of phytophysiology of the Institute of Horticulture of the National Academy of Agrarian Sciences of Ukraine. The method is based on three stages: 1 - sampling for freezing; 2 - direct freezing; 3 - microscopic analysis of damage degree to annual increments (Potanin et al., 2005; Hrokholskyi et al., 2009).

Sampling and experiments were performed during the period of deep and forced calmness of plants (February 2018), when the ambient temperature minimum was reached -20°C. The artificial freezing was performed in a freezer for scientific researches CRO/400/40 with a gradual decrease in temperature by 5°C to –25°C and –30°C. Assessment of the damage degree was carried out on a 6-point scale of M.O. Solovyova (Solovyova, 1982) in the modification of D.V. Potanin, V.V. Hrokholskyi and O.I. Kitaev (2005).

During the anatomical and microscopic evaluation of one-year increment, the level of damage to individual tissues (bark, cambium, wood and core) was determined by visual grow browning on the transversal section. After the final calculation of the degree of tissue damage, the obtained score was multiplied by a conditional significance factor, which was 6 for bark, 8 for cambium, 4 for wood and 2 for core. As a result, the total percentage of damage to individual tissue and part of the one-year increment was obtained.

The experiment was conducted in compliance with all parameters: correct sampling; use of three repetitions; compliance with the freezing regime; a homogeneous method for determining tissue damage. Analysis of variance was calculated using t-test methods according to Dospiehov (1985). Statistics are processed in the program StatSoft STATISTICA 12.

RESULTS AND DISCUSSIONS

During the anatomical and microscopic evaluation of one-year increment, the level of damage to individual tissues (bark, cambium, wood and core) was determined by visual grow browning on the transversal section. The highest damage was obtained in the apical and middle parts of the shoot under the bud, which is typical for all experimental species.

In the apical part of the shoot, the bark and cambium are most severely damaged. Thus, this indicator (phloem damage) is 0.5-4.0 points (during control), 1.0-4.5 points (at –25°C), 1.6-4.5 points (at –30°C), for plants of different species. Cambium damage is 0.3-3.0 points, 0.8-4.5 points, and 1.2-4.5 points, respectively. Damage to the wood of the top of the shoot varies between 0.5-2.7 points (during control), 0.8-4.5 points (at –25°C) and 1.3-4.5 points (at –30°C). But the lowest damage is to the core of the top of the shoot 0.6-1.5 points, 0.8-1.5 and 1.3-2.5 points, respectively. The middle of the shoot is the least sensitive to low temperatures. Tissue damage of the internodes differs only by 0.2-0.7 points (within the species) and is 0.3-1.0 points (during control), 0.7-1.8 points (at –25°C) and 1.0-3.5 points (for –30°C). Damage to the tissues of the middle of the shoot under the bud has intermediate values: it's on 0.5 points more than in the internodes, but 0.3 less than the apical part. Such a gradation of damage may be associated with insufficient maturation of tissues concentrated directly at the top of the shoot (Musiienko, 2001). Bud damage is: during the control sample - 0.5-4.5 points, under the influence of temperature –25°C - 1.5-2.5 points, at –30°C - 1.8-4.5 points.

After the final calculation of the degree of tissue damage, the obtained score was multiplied by a conditional significance factor. According to the results of statistical data processing, the total percentage of damage to individual tissues and part of the one-year increment - damage index (Table 1).

Table 1. Evaluation of the damage degree to plant tissues of introduced species by direct laboratory freezing

Experimental conditions, ºC	The damage degree to tissues of different parts of the shoot, score (mean)/damage index, %												
	The top				The middle				Through the bud				
	Bark	Cambium	Wood	Core	Bark	Cambium	Wood	Core	Bark	Cambium	Wood	Core	Bud
Aesculus × carnea Zeyh.													
Checkup	1.2/7.2	0.7/5.6	0.5/2.0	0.6/1.2	1.0/6.0	0.8/6.4	0.5/2.0	0.8/1.6	1.0/6.0	0.8/6.4	0.6/2.4	0.8/1.6	1.2/24.0
–25	1.5*/9.0	1.0*/8.0	1.2*/4.8	1.5*/3.0	1.3*/7.8	1.0*/8.0	0.8*/3.2	1.3*/2.6	1.5*/9.0	1.0*/8.0	0.7*/2.8	1.5*/3.0	1.5*/30.0
–30	2.7*/16.2	2.0*/16.0	1.8*/7.2	2.0*/4.0	2.0*/12.0	1.8*/14.4	2.0*/8.0	2.3*/4.6	2.7*/16.2	1.8*/14.4	1.7*/6.8	2.2*/4.4	3.5*/70.0
Rhus typhina L.													
Checkup	4.0/24.0	3.0/24.0	2.7/10.8	1.5/3.0	0.7/4.2	0.7/5.6	0.8/3.2	1.5/3.0	0.7/4.2	0.5/4.0	0.8/3.2	1.5/3.0	0.5/10.0
–25	4.5*/27.0	4.5*/36.0	4.5*/18.0	1.5/3.0	1.0*/6.0	0.8*/6.4	1.5*/6.0	1.5/3.0	1.2*/7.2	1.0*/8.0	1.5*/6.0	1.5/3.0	2.5*/50.0
–30	4.5*/27.0	4.5*/36.0	4.5*/18.0	1.8*/3.6	3.3*/19.8	3.0*/24.0	3.5*/14.0	2.8*/5.6	3.5*/21.0	3.0*/24.0	3.5*/14.0	3.5*/7.0	4.5*/90.0
Gleditsia triacanthos L.													
Checkup	0.6/3.6	0.5/4.0	0.7/2.8	1.3/2.6	0.5/3. 0	0.3/2.4	0.6/2.4	1.1/2.2	0.6/3.6	0.5/4.0	0.7/2.8	1.0/2.0	1.5/30.0
–25	1.0*/6.0	0.8*/6.4	1.0*/4.0	1.5*/3.0	1.0*/6.0	0.8*/6.4	1.2*/4.8	1.4*/2.8	1.0*/6.0	0.8*/6.4	1.0*/4.0	1.5*/3.0	2.0*/40.0
–30	2.0*/12.0	1.8*/14.4	2.0*/8.0	2.3*/4.6	1.8*/10.8	1.5*/12.0	1.5*/6.0	2.5*/5.0	1.4*/8.4	1.2*/9.6	1.2*/4.8	1.8*/3.6	2.2*/44.0
Cercidiphyllum japonicum Sieb. Et Zucc.													
Checkup	0.5/3.0	0.5/4.0	0.6/2.4	0.5/1.0	0.5/3.0	0.5/4.0	0.5/2.0	0.6/1.2	0.6/3.6	0.5/4.0	0.5/4.0	0.6/1.2	0.8/16.0
–25	1.0*/6.0	0.8*/6.4	1.0*/4.0	0.8*/1.6	1.0*/6.0	1.0*/8.0	1.0*/4.0	1.0*/2.0	0.8*/4.8	0.8*/6.4	0.8*/3.2	0.8*/1.6	1.5*/30.0
–30	1.6*/9.6	1.2*/9.6	1.3*/5.2	1.3*/2.6	1.8*/10.8	1.3*/10.4	1.3*/5.2	1.3*/2.6	1.5*/9.0	1.0*/8.0	1.3*/5.2	1.6*/3.2	1.8*/36.0

Experimental conditions, °C	The damage degree to tissues of different parts of the shoot, score (mean) / damage index, %												
	The top				The middle				Through the bud				Bud
	Bark	Cambium	Wood	Core	Bark	Cambium	Wood	Core	Bark	Cambium	Wood	Core	
Acer platanoides 'Globosum'													
Checkup	0.6 / 3.6	0.5 / 4.0	0.6 / 2.4	0.6 / 1.2	0.5 / 3.0	0.3 / 2.4	0.5 / 2.0	0.5 / 1.0	0.8 / 4.8	0.5 / 4.0	0.6 / 2.4	0.6 / 1.2	0.6 / 12.0
–25	1.5* / 9.0	0.8* / 6.4	0.8* / 3.2	0.8* / 1.6	1.3* / 7.8	0.8* / 6.4	0.8* / 3.2	0.8* / 1.6	1.5* / 9.0	1.0* / 8.0	1.0* / 4.0	0.8* / 1.6	1.5* / 30.0
–30	2.0* / 12.0	2.0* / 16.0	1.7* / 6.8	1.3* / 2.6	1.8* / 10.8	1.2* / 9.6	1.0* / 4.0	1.0* / 2.0	2.3* / 13.8	1.5* / 12.0	1.3* / 5.2	1.2* / 2.4	2.0* / 40.0
Phellodendron amurense Rupr.													
Checkup	0.8 / 4.8	0.5 / 4.0	0.8 / 3.2	1.0 / 2.0	0.8 / 4.8	0.8 / 6.4	0.6 / 2.4	1.2 / 2.4	1.0 / 6.0	0.8 / 6.4	0.8 / 3.2	1.4 / 2.8	1.5 / 30.0
–25	1.5* / 9.0	1.3* / 10.4	1.3* / 5.2	0.8* / 1.6	1.0* / 6.0	0.8 / 6.4	0.8* / 3.2	1.5* / 3.0	1.5* / 9.0	1.3* / 10.4	1.2* / 4.8	1.5* / 3.0	2.0* / 40.0
–30	3.0* / 18.0	2.5* / 20.0	2.0* / 8.0	1.5* / 3.0	2.5* / 15.0	2.0* / 16.0	1.8* / 7.2	1.8* / 3.6	3.0* / 18.0	2.0* / 16.0	2.3* / 9.2	2.3* / 4.6	4.0* / 80.0
Catalpa hybrida Spath.													
Checkup	1.2 / 7.2	1.0 / 8.0	1.2 / 4.8	1.2 / 2.4	0.6 / 3.6	0.5 / 4.0	0.6 / 2.4	0.5 / 1.0	0.8 / 4.8	0.6 / 4.8	0.8 / 3.2	0.6 / 1.2	1.2 / 24.0
–25	2.5* / 15.0	1.7* / 13.6	1.8* / 7.2	1.2 / 2.4	1.8* / 10.8	1.5* / 12.0	1.8* / 7.2	1.5* / 3.0	2.0* / 12.0	2.0* / 16.0	1.8* / 7.2	1.0* / 2.0	2.3* / 46.0
–30	4.0* / 24.0	3.5* / 28.0	3.5* / 14.0	1.5* / 3.0	2.5* / 15.0	2.0* / 16.0	2.2* / 8.8	1.8* / 3.6	3.0* / 18.0	2.5* / 20.0	2.3* / 9.2	1.5* / 3.0	4.0* / 80.0
Magnolia × soulangeana Soul.-Bod.													
Checkup	0.5 / 3.0	0.7 / 5.6	1.0 / 4.0	1.0 / 2.0	0.6 / 3.6	0.5 / 4.0	0.8 / 3.2	0.5 / 1.0	0.7 / 4.2	0.6 / 4.8	0.7 / 2.8	0.5 / 1.0	0.7 / 14.0
–25	1.8* / 10.8	1.5* / 12.0	1.8* / 7.2	1.3* / 2.6	1.5* / 9.0	1.5* / 12.0	1.3* / 5.2	1.2* / 2.4	1.8* / 10.8	1.5* / 12.0	1.7* / 6.8	1.3* / 2.6	2.5* / 50.0
–30	3.0* / 18.0	2.5* / 20.0	2.7* / 10.8	1.5* / 3.0	2.8* / 16.8	2.5* / 20.0	2.3* / 9.2	1.7* / 3.4	3.0* / 18.0	3.0* / 24.0	2.3* / 9.2	2.0* / 4.0	3.5* / 70.0
Liriodendron tulipifera L.													
Checkup	0.5 / 3.0	0.3 / 2.4	0.5 / 2.0	0.6 / 1.2	0.5 / 3.0	0.3 / 2.4	0.7 / 2.8	0.6 / 1.2	0.5 / 3.0	0.5 / 4.0	0.7 / 2.8	0.5 / 1.0	0.5 / 10.0
–25	1.0* / 6.0	1.0* / 8.0	1.5* / 6.0	1.0* / 2.0	0.8* / 4.8	0.7* / 5.6	0.7 / 2.8	0.7* / 1.4	1.0* / 6.0	1.0* / 8.0	1.2* / 4.8	1.1* / 2.2	1.5* / 30.0
–30	3.5* / 21.0	3.5* / 28.0	3.5* / 14.0	1.5* / 3.0	3.0* / 18.0	3.0* / 24.0	3.0* / 12.0	1.2* / 2.4	3.0* / 18.0	3.0* / 24.0	3.0* / 12.0	1.6* / 3.2	3.5* / 70.0

Note: the mark (*) means that the indicators of the offspring have a significant difference compared to the control (tф ≥ t0.5)

The estimation of degree damage of tissues on kinds is established for the comparative analysis of frost resistance of introducers and, accordingly, we summed up on parts of a shoot (Table 2).

The difference in data on control options within species reaches up to 51.8%. There is a variation between the indicators of different parts of the shoot - up to 62.6 % at a temperature of –25°C, and at –30°C - 0.8-38.2%.

Cercidiphyllum japonicum (10.4-27.0%) was found to have the least damage of the tissues of the shoot top among the experimental objects. Moreover, the maximum frost damage of this species reaches only 29.0% (at –30°C, the middle of the shoot).

Table 2. Total damage index of shoots

Experimental conditions, °C	Total damage index of shoots, %			
	The top of bud	The midst of bud	The section through the bud	The bud
Aesculus × *carnea* Zeyh.				
Checkup	16.0	16.0	16.4	24.0
–25	24.8	21.6	25.8	30.0
–30	43.4	39.0	41.8	70.0
Rhus typhina L.				
Checkup	61.8	16.0	14.4	10.0
–25	84.0	21.4	24.4	50.0
–30	84.6	63.4	66.0	90.0
Gleditsia triacanthos L.				
Checkup	13.0	10.0	12.4	30.0
–25	19.4	20.0	19.4	40.0
–30	39.0	33.8	26.4	44.0
Cercidiphyllum japonicum Sieb. Et Zucc.				
Checkup	10.4	10.2	12.8	16.0
–25	18.0	20.0	16.0	30.0
–30	27.0	29.0	25.4	36.0
Phellodendron amurense Rupr.				
Checkup	14.0	16.0	18.4	30.0
–25	26.2	18.6	27.2	40.0
–30	51.0	41.8	47.8	80.0
Catalpa hybrida Spath.				
Checkup	22.4	11.0	14.0	24.0
–25	38.2	33.0	37.2	46.0
–30	69.0	43.4	50.2	80.0
Magnolia × *soulangeana* Soul.-Bod.				
Checkup	14.6	11.8	12.8	14.0
–25	32.6	28.6	32.2	50.0
–30	51.8	49.4	55.2	70.0
Liriodendron tulipifera L.				
Checkup	8.6	9.4	10.8	10.0
–25	22.0	14.6	21.0	30.0
–30	66.0	56.4	57.2	70.0
Acer platanoides ‘Globosum’				
Checkup	11.2	8.4	12.4	12.0
–25	20.2	19.0	22.6	30.0
–30	37.4	26.4	33.4	40.0

The highest index of damage to the top (84.6%) was obtained in samples of *Rhus typhina* at a temperature of –30°C, as well as at other temperature variants - 61.8% (checkup) and 84.0% (at –25°C) (Figure 1).

The lowest indices of tissue damage in the middle of the shoot were recorded in: *Liriodendron tulipifera* - 14.6% (at –25°C), *Acer platanoides* ‘Globosum’ - 8.4% (control option) and 26.4% (at –30°C). The maximum indices reach 63.4 % (–30°C) and 16% (control) in *Rhus typhina*, and at –25°C its 28.6% in *Magnolia* × *soulangeana* (Figure 2).

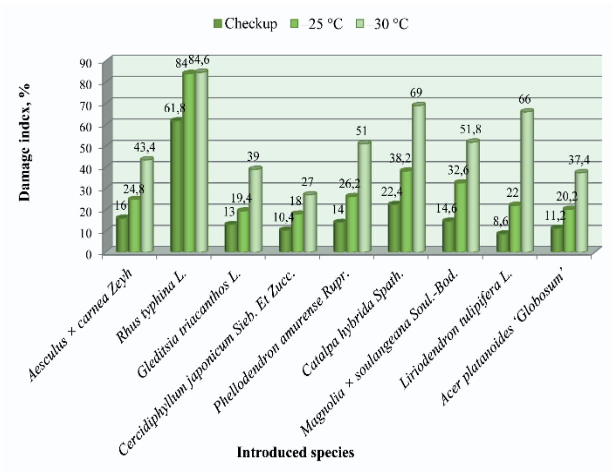

Figure 1. Indicators of the damage degree of the top of the shoot

Similar indicators of the damage degree were obtained in the analysis of tissues in a section through the bud. The maximum index of damage under the action of temperature –30°C is 66% in *Rhus typhina*, 57.2% *in Liriodendron tulipifera*, 55.2% in *Magnolia × soulangeana*, 50.2% in *Catalpa hybrida*.

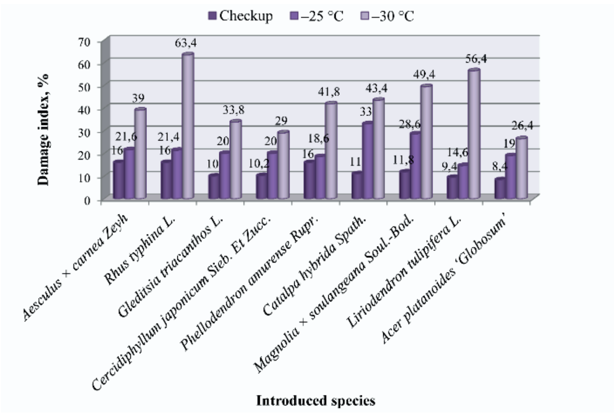

Figure 2. Indicators of the damage degree of the middle of the shoot

The plants of these taxons went through the maximum experimental temperature: *Cercidiphyllum japonicum* (25.4%), *Gleditsia triacanthos* (26.4%) and *Acer platanoides* ‘Globosum’ (33.4%).

The remaining specimens of the studied species received damage of low degree (12.4% - *Gleditsia triacanthos*, *Acer platanoides* ‘Globosum’) and medium degree (47.8% - *Phellodendron amurense*) (Figure 3).

It is worth noting that the greatest damage is suffered by the bud during the effect of low temperatures. The largest indices were obtained by buds: *Rhus typhina* - 90%, *Catalpa hybrida* and *Phellodendron amurense* - 80% each (Figure 4).

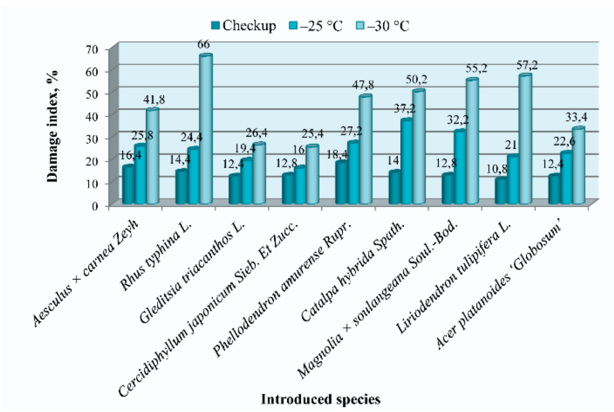

Figure 3. Indicators of the damage degree of the shoot through the bud

According to the results of statistical data processing, taking into account the viability of the bud, the total score of damage to all parts of the shoots by species was summed (Figure 5).

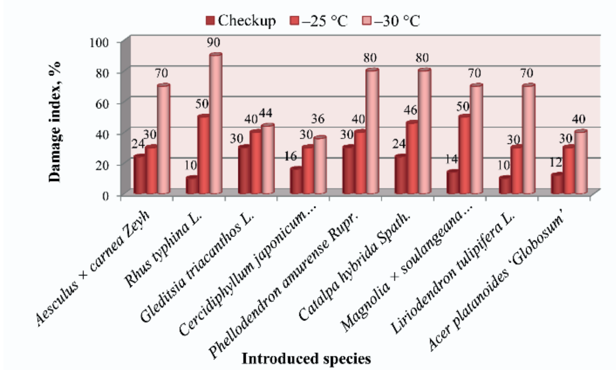

Figure 4. Indicators of the damage degree of the bud

As we can see on the diagram, the least tissue damage was received by *Cercidiphyllum japonicum* (7.2-18.3 points), *Phellodendron amurense* (7.2-20.3 points) and *Gleditsia triacanthos* (9.9-23.2 points). Even the damage of –30°C had reduced vitality by only a third. These results testify to rather high frost resistance of the specified representatives and their further prospects of introduction in natural conditions with the lowered temperatures.

Among the obtained data it is worth to distinguish the indicators of damage of *Rhus typhina*, which already received 18.9 points of damage during the checkup. This result of damage is primarily due to the differentiation of the assessment - the damage index of the top of the shoot is 61.8-84.6%, and the tissues of the middle of the shoot is 16.0-63.4%.

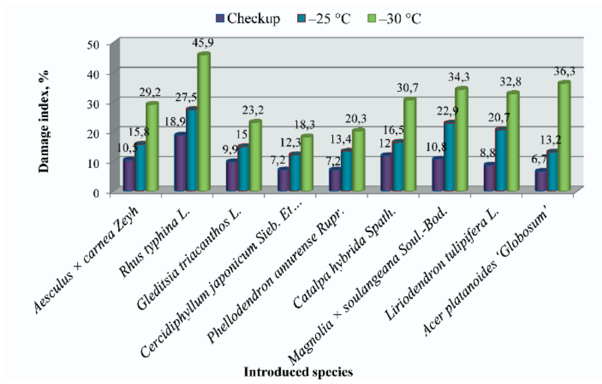

Figure 5.The assessment of the frost resistance of introducers (total damage score)

A similar damage degree of *Rhus typhina* shoots (71-80%) was obtained in Kyiv on Bazhan Avenue, the authors justify this with a high concentration of pollutants and a significant anthropogenic impact on green plantations (Borshchevskyi & Kytaiev, 2013). The experimental samples were taken from street planting in the city center (Copernicus Street), so this factor most likely influenced the results in our study. It is also worth noting that the samples of shoots were taken from young plants (5-7 years), which haven't yet been properly adapted to adverse environmental factors. During the analysis of frost damage, it is obvious that all the introducers didn't receive critical values for checkup –20°C and for temperature –25°C (Figures 6, 7). The presented indicators aren't critical and acceptable for normal plant life, which is fully reflected in the viability of the buds (Figure 8).

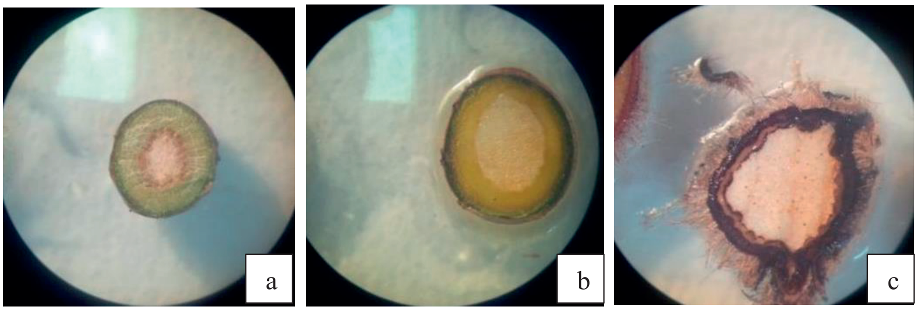

Figure 6. Section of the apical part of the shoot under the effect of temperature –25°C: a - *Gleditsia triacanthos* L.; b - *Cercidiphyllum japonicum* Sieb. Et Zucc.; c - *Rhus typhina* L.

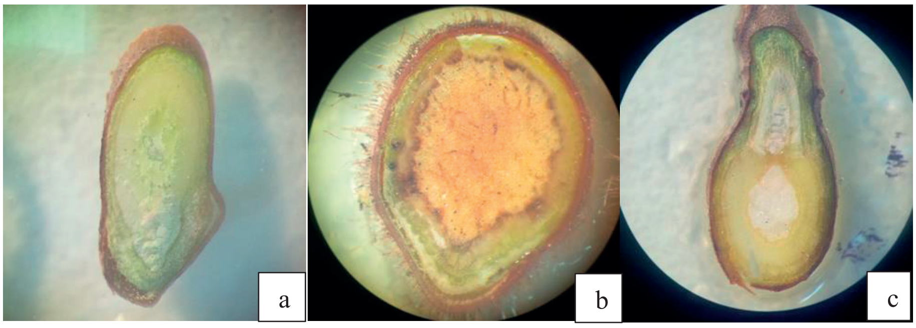

Figure 7. Section of the shoot through the bud under the effect of temperature –25°C: *a* - *Cercidiphyllum japonicum* Sieb. Et Zucc.; *b* - *Rhus typhina* L.; *c* - *Liriodendron tulipifera* L.

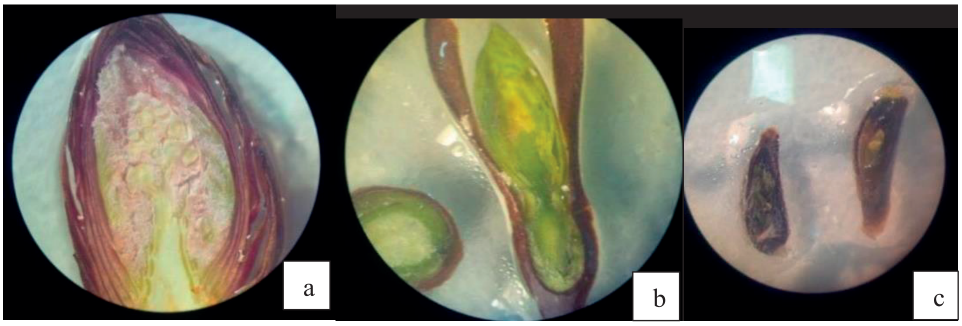

Figure 8. Section of the bud under the effect of temperature –25°C: *a* - *Aesculus × carnea* Zeyh.; b - *Liriodendron tulipifera* L.; *c* - *Magnolia × soulangeana* Soul.-Bod.

According to the obtained total indices of tissue damage of all parts of the shoot, their statistical processing was performed. In the variant checkup species: *Magnolia soulangeana*, *Liriodendron tulipifera*, *Acer platanoides* 'Globosum' and *Cercidiphyllum japonicum* belong to one cluster, and *Sorbus aucuparia*, *Phellodendron amurense*, *Catalpa hybrida*, *Aesculus × carnea*, *Gleditsia triacanthos* - to another (Figure 9).

Similarity of *Sorbus aucuparia* and *Phellodendron amurense* species, as well as *Liriodendron tulipifera* with *Acer platanoides* 'Globosum' is observed at a temperature of –25 °C. Other variants, except *Rhus typhina*, formed a separate cluster (Figure 10).

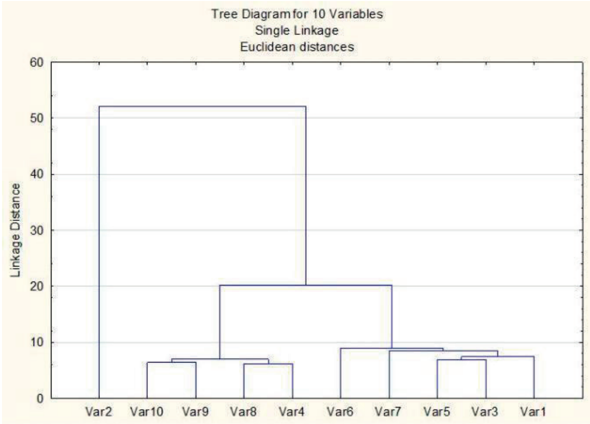

Figure 9. Dendrogram of similarity of species according to the total damage index (checkup option): Var1 - *Aesculus × carnea* Zeyh; Var2 - *Rhus typhina* L.; Var3 - *Gleditsia triacanthos* L.; Var4 - *Cercidiphyllum japonicum* Sieb. Et Zucc.; Var5 - *Sorbus aucuparia* L.; Var6 - *Phellodendron amurense* Rupr.; Var7 - *Catalpa hybrida* Spath.; Var8 - *Magnolia soulangeana* Soul.-Bod.; Var9 - *Liriodendron tulipifera* L.; Var10 - *Acer platanoides* 'Globosum'

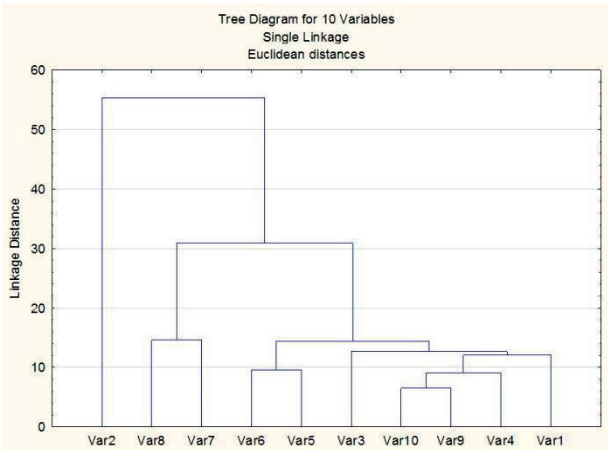

Figure 10. Dendrogram of species similarity (variant –25°C): Var1 - *Aesculus × carnea* Zeyh; Var2 - *Rhus typhina* L.; Var3 - *Gleditsia triacanthos* L.; Var4 - *Cercidiphyllum japonicum* Sieb. Et Zucc.; Var5 - *Sorbus aucuparia* L.; Var6 - *Phellodendron amurense* Rupr.; Var7 - *Catalpa hybrida* Spath.; Var8 - *Magnolia soulangeana* Soul.-Bod.; Var9 - *Liriodendron tulipifera* L.; Var10 - *Acer platanoides* 'Globosum'

The studed species were grouped in a new way at a temperature of –30°C: *Gleditsia triacanthos*, *Cercidiphyllum japonicum* and *Acer platanoides* 'Globosum' form one cluster, and other variants, except *Aesculus × carnea* - the second (Figure 11).

The dendrogram of Figure 12 is constructed according to the complex of all features. As we can see in the dendrogram of similarity, *Rhus typhina* forms a separate branch, which indicates its uniqueness. This species is specific to all variants of the experiment. This again confirms the fact that its physiological state reflects the influence of urbanized factors of the city environment.

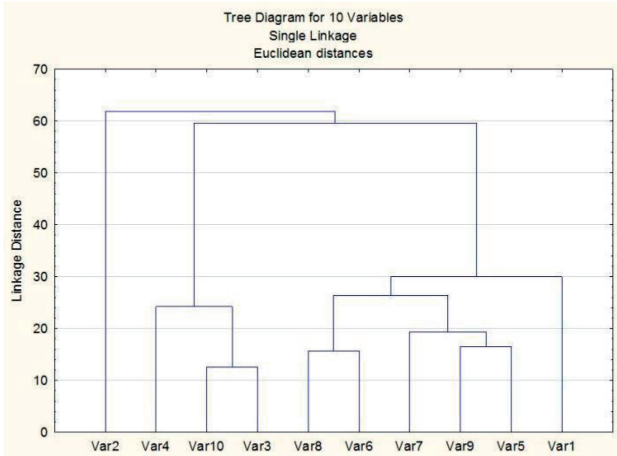

Figure 11. Dendrogram of species similarity (variant –30°C): Var1 - *Aesculus × carnea* Zeyh; Var2 - *Rhus typhina* L.; Var3 - *Gleditsia triacanthos* L.; Var4 - *Cercidiphyllum japonicum* Sieb. Et Zucc.; Var5 - *Sorbus aucuparia* L.; Var6 - *Phellodendron amurense* Rupr.; Var7 - *Catalpa hybrida* Spath.; Var8 - *Magnolia soulangeana* Soul.-Bod.; Var9 - *Liriodendron tulipifera* L.; Var10 - *Acer platanoides* 'Globosum'

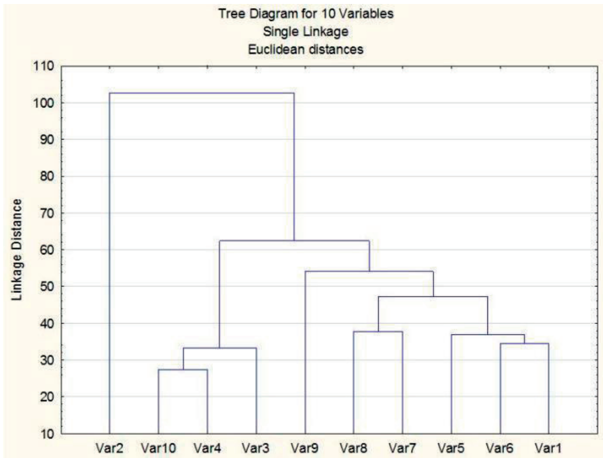

Figure 12. Dendrogram of similarity of complex assessment: Var1 - *Aesculus × carnea* Zeyh; Var2 - *Rhus typhina* L.; Var3 - *Gleditsia triacanthos* L.; Var4 - *Cercidiphyllum japonicum* Sieb. Et Zucc.; Var5 - *Sorbus aucuparia* L.; Var6 - *Phellodendron amurense* Rupr.; Var7 - *Catalpa hybrida* Spath.; Var8 - *Magnolia soulangeana* Soul.-Bod.; Var9 - *Liriodendron tulipifera* L.; Var10 - *Acer platanoides* 'Globosum'

Species such as *Acer platanoides* 'Globosum', *Cercidiphyllum japonicum* and *Gleditsia triacanthos* belong to one cluster, which is explained by their resistance and adaptability to low temperatures in the Lutsk city.

The remaining studied species form the second cluster group, which is due to their relative frost resistance, depending on the temperatures and the damage degree to different tissues of the shoot.

However, *Liriodendron tulipifera* differs, it occupies an intermediate position. This is explained by the fact that in the control variants (–20°C) and –25°C, the optimal values were obtained in all parts of the shoot, and at a temperature of –30 °C the values are close to critical in all diagrams.

All studied species of introduced plants in terms of frost resistance are suitable for landscaping in the Lutsk city, taking into account the winter minimum temperature, which usually doesn't exceed the above indicators.

However, it isn't recommended to plant *Rhus typhina*, *Magnolia × soulangeana*, *Catalpa hybrida*, *Liriodendron tulipifera* and *Acer platanoides* 'Globosum' in open street plantings in the city center, which are subject to significant anthropogenic pressure according to the results obtained at –30 °C experiment. It is desirable to plant them in groups in places protected from adverse effects (parks, gardens, etc.).

CONCLUSIONS

According to the results of laboratory freezing of one-year shoots, we can arrange research objects according to the level of frost resistance in the following sequence (in the direction of its reduction): *Cercidiphyllum japonicum* Sieb. Et Zucc. => *Acer platanoides* 'Globosum' => *Gleditsia triacanthos* L. => *Aesculus × carnea* Zeyh => *Liriodendron tulipifera* L. => *Phellodendron amurense* Rupr. => *Magnolia × soulangeana* Soul.-Bod. => *Catalpa hybrida* Spath. => *Rhus typhina* L.

According to the level of frost resistance, the following are promising for further testing and cultivation for all types of plantations in the conditions of Lutsk: *Cercidiphyllum japonicum*, *Acer platanoides* 'Globosum', *Gleditsia triacanthos* and *Aesculus × carnea* Zeyh.

The following plants are recommended for creation of group landings in the places protected from influence of adverse factors: *Rhus typhina*, *Magnolia soulangeana*, *Catalpa hybrida, Liriodendron tulipifera* and *Phellodendron amurense.*

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