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DROUGHT RESISTANCE MONITORING OF INTRODUCED TALL TREES SPECIES UNDER CHANGED URBAN CLIMATIC CONDITIONS

Background. ***Landscaping of urban environments significantly mitigates the negative effects of "urban heat islands", which in turn has a positive effect on many aspects of human life. Therefore, the purpose of our research was to identify drought-tolerant rare and decorative species of woody plants with further recommendation for their inclusion in the ecosystems of the urban environment.***

Methods. ***For research, we selected from the collections of the Botanical Garden named after acad. O.V. Fomina 25 highly decorative species of trees with a height from 10 to 50 m, which come from temperate and continental climate zones. Among them, 14 species are uncommon and 11 species are widespread in mass culture in the Polissia and Forest-Steppe zone of Ukraine. The drought resistance test was conducted twice: in early June and also in early September. Relative drought resistance was assessed by following parameters: tissue hydration and water loss per unit time.***

Results. ***According to the results of the study, most of the 25 species of tall trees showed a high or average level of drought resistance. The most drought-resistant light-loving and shade-tolerant species were recommended. Species that may require additional care during cultivation (Phelodendron amurense and Styphnolobium japonicum) have been identified, which must be taken into account when landscaping urban areas.***

Conclusions. ***Among shade-tolerant trees, the following species can be recommended for cultivation in urban conditions as highly drought-resistant: Acer mandshuricum, Acer velutinum, Corylus colurna and Prunus padus. The following light-loving plants turned out to be the most drought-resistant: Liriodendron chinense, Ginkgo biloba, Acer saccharinum, Catalpa bignonioides, Catalpa fargesii and Tilia europea.***

Keywords: ***drought resistance, landscaping of cities, rare plants.***

Background

The importance of increasing and expanding the area of green spaces in cities in order to reduce the effects of "urban heat islands" in the summer, as well as to improve the comfort, health and safety of local communities, is emphasized by scientists from different countries (Keenan et al., 2016; Zhao et al., 2018; Branas et al., 2018). Planting trees contributes to the cooling of the earth's surface and the air, the air is saturated with O_2 and purified from harmful substances, phytoremediation and protection of the soil from degradation is observed (Önder & Akay, 2014). The selection of drought-resistant plants for landscaping increases their viability in urban conditions, and also has a positive economic effect, as it reduces the costs of their maintenance. The selection of rare, uncommon drought-resistant species will not only allow recommending new plants for landscaping urban environments, but will also contribute to the preservation of phytodiversity, which is prescribed in the "National Strategy of the State Environmental Policy of Ukraine".

Global climate change is often accompanied by sudden changes in temperature, a significant increase in precipitation in some regions, and increased drought in others. According to the latest forecasts, such phenomena will occur more often and will be more extreme (Allen et al., 2010; Reyer et al.,2015). Such climatic changes in some places reduce the viability of some native plants, but, on the other hand, there is an opportunity to grow plants from temperate climate zones, which are not yet widely cultivated in Ukraine. Unfortunately, similar problems are currently present all over the world (Lanza & Stone, 2016; Kannenberg et al., 2019). So, for example, Lanza K. and co-authors studied the historical range of distribution of tree species in the United States in view of the migration of winter hardiness zones to the north with climate change (Lanza & Stone, 2016). The goal of their work was to identify tree species that are likely to remain well adapted to urban climates in the future. Under urbanized conditions complicated by climate change, the survival of plant species depends on the complex of their adaptations. However, until recently, agricultural plants (corn, wheat, soy, some fruit trees, etc.) were the objects of study of the mechanisms of resistance to the effects of, in particular, drought (Zandalinas et al., 2016; Hasanuzzaman et al., 2019; Hussain et al., 2019).

In this regard, the aim of the work was to identify and research the most promising drought-tolerant rare and decorative species of woody plants from the collection of the Botanical Garden named after Acad. O.V. Fomina with a further recommendation to include them in the ecosystems of the urban environment.

Methods

For research, we selected from the collections of the Botanical Garden named after Acad. O.V. Fomina 25 highly decorative species of woody plants with a height from 10 to 50 m. Kyiv is located in the North of Ukraine, on the border between Polissia and Forest Steppe; the climate of the capital is defined as moderately continental, with mild winters and warm summers (Climate of Kyiv, 2010). Among the introduced species selected by us, there were 14, which originate from the zones of temperate and continental climates, are not common in culture in the Polissia and Forest-Steppe zones of Ukraine (*Acer mandshuricum* Maxim., *Acer velutinum* Boiss., *Castanea sativa* Mill., *Catalpa bignonioides* Walter, *Catalpa fargesii* Bureau, *Fagus orientalis* Lipsky, *Ginkgo biloba* L., *Juglans nigra* L., *Liriodendron chinense* (Hemsl.) Sarg., *Parrotia persica* C.A. Mey., *Paulownia tomentosa* Steud., *Platanus × hispanica*

Mill. Ex Münchh., *Pterocarya pterocarpa* Kunth ex I.Iljinsk., *Styphnolobium japonicum* (L.) Schott).

As well as 11 introduced and native species that come from temperate and continental climate zones, widely distributed in mass culture in the Polissia and Forest-Steppe zone of Ukraine (*Acer saccharinum* L., *Aesculus* × *carnea* Zeyh., *Aesculus hippocastanum* L., *Corylus colurna* L., *Fagus sylvatica* L., *Phelodendron amurense* Rupr., *Prunus padus* L., *Quercus rubra* L., *Robinia pseudoacacia* L., *Tilia europea* L., *Tilia platyphyllos* Scop.).

In addition to being highly decorative, most of the species we have chosen are rare and endangered. Such species as: *Acer mandshuricum, Castanea sativa, Corylus colurna, Fagus orientalis, Fagus sylvatica, Juglans nigra, Prunus padus, Quercus rubra* have the degree of rarity LC; *Aesculus hippocastanum* – Vul, *Catalpa bignonioides* – DD, *Ginkgo biloba* – Enand *Liriodendron chinense* – NT. The degree of rarity of plant species is established according to iucnredlist.org, version 2021-2.

The staff of the Botanical Garden conducted long-term visual observations of the woody plants used in this study. These plants proved to be hardy in our climate. However, growing in garden collections involves additional care, which is often absent in urban landscaping. Therefore, we conducted additional studies of relative drought resistance indicators in order to select the most hardy species for cultivation in the urban environment.

The test on drought resistance was carried out twice: in early June, when the temperatures are already high, but the leaves on the trees are still young, and also in early September, when the temperatures are still high, the amount of precipitation is low, but the leaves have already acquired all characteristics of their species.

The winter of 2022 in Kyiv had little snow, the spring and summer of 2022 were very dry, according to the observations of the weather station Boris Sresnevsky Central Geophysical Observatory (https://www.cgo-sreznevskyi.kyiv.ua). Spring started a month earlier. The spring months, except for March, were colder than the climatic norm, and the amount of precipitation in the capital during the spring was 87 mm, which is 59 % of the climatic norm. The spring of 2022 was among the ten driest from 1855. The average air temperature in summer in Kyiv was +21.6 ºC. This exceeded the climatic norm by 1.2 ºC. According to the amount of precipitation, the summer in Kyiv was among the twenty driest since 1891. Such weather conditions contributed to conducting research on drought resistance.

Relative drought resistance was assessed by measuring the following parameters of the water regime: leaf water content (WC) and water loss per unit time (WL) ($n = 6$ for the species) and based on the relative drought resistance assessment scale (Table 1):

WC=(a-b)/a×100, where WC– leaf water content, %; a – weight of wet raw, g; b – weight of dry raw, g;

WL=(M1-M2)/M3×100, where WL – water loss in 1 h of wilting, %; M1 – mass of leaves before wilting, g; M2 – mass of leaves after 2 or 4 h of wilting, g; M3 – weight of dry raw, g.

Table 1

Rating scale of water regime parameters for determining relative drought resistance

Assessment of drought resistance	WC, %	WL, %
Low	59,9 and <	11,1 and >
Average	60,0 – 69,9	10,1 – 11,0
High	70,0 and >	to 10,0

Statistical processing of the results was done using the Prism Graphpad 8 program (GraphPad; La Jolla, CA, USA). The values for different groups were compared by ANOVA followed by Tukey's multiply comparison test. Tree species were compared with each other, as well as the June group with the group studied in September.

Results

One of the relative indicators of drought resistance is leaf water content (Fig. 1). *Liriodendron chinense, Aesculus hippocastanum* and *Ginkgo biloba* are the most drought-resistant species according to this indicator among large trees both in spring and in early autumn. Increased water content indicates the presence in the leaves of a sufficient supply of water for the vital activity of plants in case of dry conditions. Also, a high rate of water was found in early June in young leaves of *Acer saccharinum, Aesculus* × *carnea, Acer velutinum, Catalpa bignonioides*, *Catalpa fargesii, Juglans nigra*, *Paulownia tomentosa*, *Phelodendron amurense, Styphnolobium japonicum, Tilia europea*. This indicator is especially important for young leaves, since they often have not yet acquired all the inherent xerophytic features.

A low rate of water content in both summer and autumn leaves was found in *Castanea sativa, Fagus orientalis, Fagus sylvatica, Parrotia persica, Prunus padus, Quercus rubra*.

Acer mandshuricum, Corylus colurna, Platanus × *hispanica, Pterocarya pterocarpa* and *Robinia pseudoacacia* showed a low level of water content of autumn tree leaves. All other studied plants were characterized by the average values of this indicator. In general, leaf water content at the beginning of summer was significantly higher than at the beginning of autumn in all studied species. A similar pattern was also observed for trees up to 10 m tall and bushes (Nuzhyna et al., 2022).

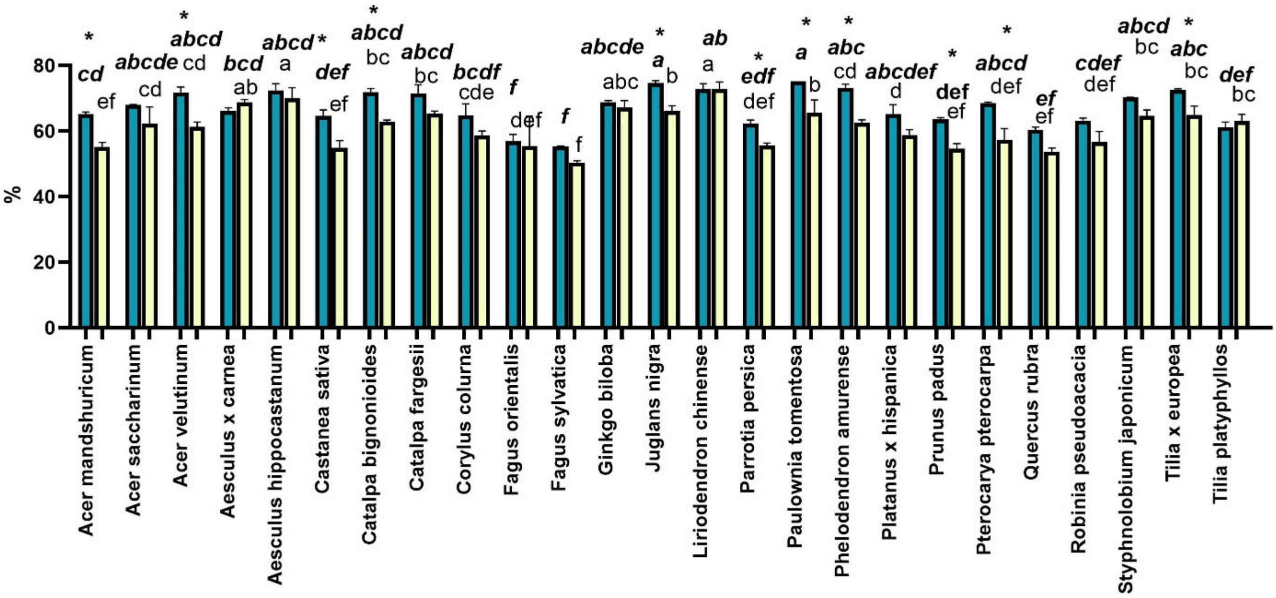

Fig. 1. Index of leaf water content (where, dark color is the value obtained in June; light color is the value obtained in September) * – *P* ≤ 0.01 significant difference, compared to the September group; identical letters in bold italics indicate no significant difference between species examined in June; same letters in regular font indicate no significant difference between different species examined in September

The water-holding capacity is characterized by the loss of water in 1 hour of wilting, this indicator was small for most of the studied species of tall trees, which is indirectly a sign of high drought resistance of plants (Fig. 2). Only such species as: *Aesculus hippocastanum* and *Phelodendron amurense* showed a large loss of water per unit time of wilting in the spring along with a small loss in the fall, which is probably related to the slower formation of immature leaves and requires especially careful care for young seedlings in the spring. Along with this, *Aesculus × carnea* and *Juglans nigra* showed an average level of drought resistance in autumn according to the water retention index. *Styphnolobium japonicum* had rather low indicators of relative drought resistance in both autumn and spring.

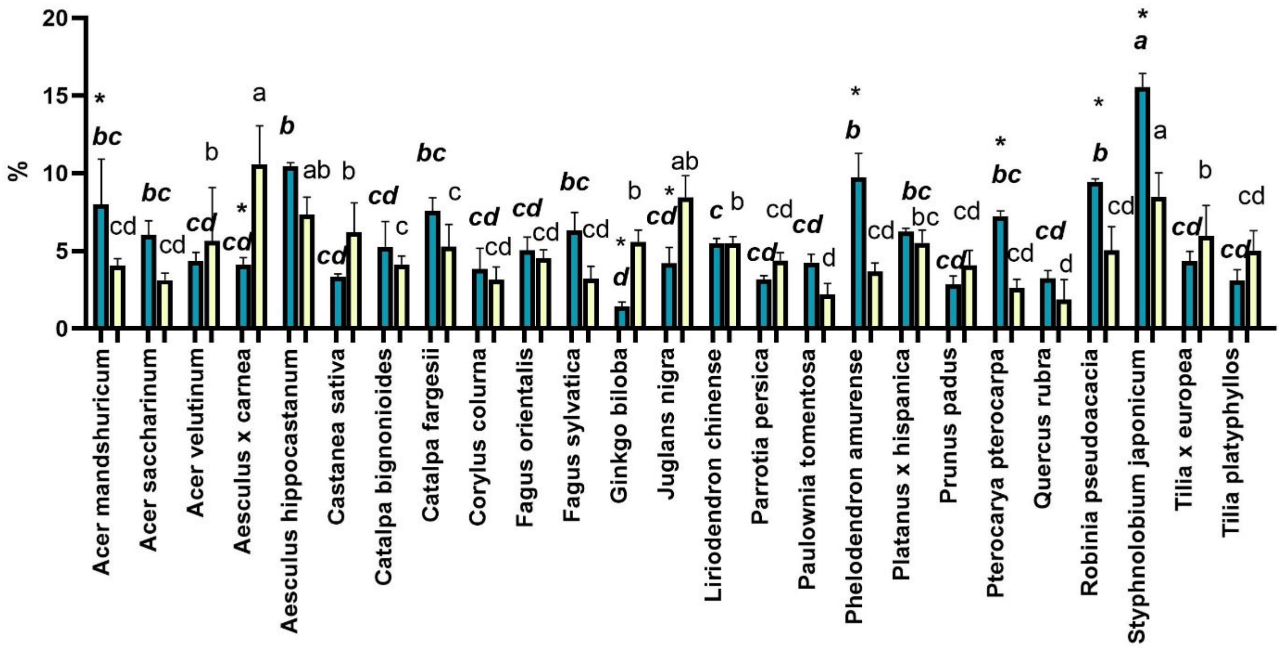

Fig. 2. Index of leaf water loss in 1 h of wilting (where, dark color is the value obtained in June; light color is the value obtained in September); * – *P* ≤ 0.01 significant difference, compared to the September group; identical letters in bold italics indicate no significant difference between species examined in June; same letters in regular font indicate no significant difference between different species examined in September

Castanea sativa, Fagus orientalis, Fagus sylvatica, Parrotia persica, Prunus padus, and *Quercus rubra* showed a lower relative drought resistance according to the leaf water content, but a high water-holding capacity. That is, the adaptation to arid conditions in these species is not aimed at the accumulation of water in the leaf, but at the development of the covering tissues of the leaf plate, with the aim of reducing water evaporation.

Most species showed an increase in drought resistance as measured by water loss in September compared to early June, possibly due to the appearance of xerophytic traits in older leaves. When growing these plants, it is especially important to increase watering in the spring for young seedlings.

Discussion and conclusions

Adaptation to drought is characterized by such anatomical and morphological features as leaf thickness, cuticular cover, number of stomata, root morphology, etc. It is the first three signs that affect the measured indicators of relative drought resistance. Also, adaptation at other levels are analyzed. Thus, although *Fagus sylvatica* and *Quercus robur* are close representatives of the same family, they adapt to arid conditions in different ways (Roman et al., 2015). Beech has a shallow root system, while oak has a deep root system, which allows efficient use of groundwater (Leuschner & Meier, 2018). Based on the results of the relative drought resistance indicators, the beeches and oaks studied by us did not reliably differ from each other, only a slight tendency towards greater drought resistance of *Quercus rubra* was observed. It should be noted that the condition of the root system is difficult to assess when growing in urban conditions, since in cities, as a rule, the growth of the root system is limited to roadways, foundations, pipelines, etc. That is why it is difficult to extrapolate the structure of the root system characteristic of the species to plants grown in the city.

Another way to withstand drought is leaf shedding, which is regulated by various phytohormones. Breeders have created polyploid poplars, which in drought conditions shed leaves similar to plants from dry tropical forests, which increased the survival of such poplars during extreme drought (Hennig et al., 2015). A similar property was found in *Liriodendron chinense, Acer velutinum, Platanus hispanica, Prunus padus, Stiphnolobium japonicum*, which is an additional protection of the plant against adverse conditions.

When creating landscape compositions, it is also necessary to take into account the relationship of plants to the intensity of lighting. According to Kolisnichenko, among the studied species, the following are shade-tolerant: *Acer mandshuricum, Acer velutinum, Corylus colurna, Fagus orientalis, Fagus sylvatica, Parrotia persica, Phelodendron amurense* and *Prunus padus* (Kolisnichenko, 2004). Since growth in shaded conditions generally involves less drying of the soil, it is possible that this may explain the lower drought tolerance of most of these species. Thus, among shade-tolerant trees, the following species can be recommended for cultivation in urban conditions as highly drought-resistant: *Acer mandshuricum, Acer velutinum, Corylus colurna* and *Prunus padus*. Growing *Phelodendron amurense* will require additional watering, which is not economically beneficial, and insufficient soil moisture is stressful for plants, which in turn increases the possibility of various diseases.

Among light-loving plants, almost all plants showed a high or medium level of drought resistance, only Styphnolobium japonicum showed a low water-holding capacity. The following light-loving plants turned out to be the most drought-resistant: *Liriodendron chinense, Ginkgo biloba*, *Acer saccharinum, Catalpa bignonioides*, *Catalpa fargesii* and *Tilia europea.*

According to the results of the study, most of the 27 species of tall trees showed a high or average level of drought resistance. Only *Phelodendron amurense* and *Styphnolobium japonicum* were characterized by a low level of drought resistance according to the measured parameters. Therefore, these species cannot be recommended for landscaping urban areas.

Authors' contributions: Natalia Nuzhyna conceived of the research idea, performed statistical analyses, wrote the paper; Natalia Nuzhyna and Iryna Ivanova collected data and discussed the results.

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МОНІТОРИНГ ПОСУХОСТІЙКОСТІ ІНТРОДУКОВАНИХ ВИДІВ ВИСОКОРОСЛИХ ДЕРЕВ ПІСЛЯ ЗМІНИ КЛІМАТИЧНИХ УМОВ УРБОПРОСТОРІВ

Вступ. ***Озеленення урбанізованих середовищ значно пом'якшує негативні ефекти "міських островів тепла", що, у свою чергу, позитивно впливає на багато аспектів життя людини. Тому метою дослідження було виявити посухотолерантні рідкісні та декоративні види деревних рослин з подальшою рекомендацією приєднання їх до екосистеми урбанізованого середовища.***

Методи. ***Для дослідження було відібрано з колекцій Ботанічного саду ім. акад. О.В. Фоміна 25 високодекоративних видів деревних рослин висотою від 10 до 50 м, які походять із зон помірного та континентального клімату. Серед них 14 видів є малопоширеними та 11 видів істотно поширені в масовій культурі в зоні Полісся і Лісостепу України. Дослід на посухостійкість проводили двічі: на початку червня, а також на початку вересня. Оцінювання відносної посухостійкості проводили за такими параметрами: оводненість тканин і втрату води за одиницю часу.***

Результати. ***За результатами дослідження більшість з 25 видів високорослих дерев показали високий або середній рівень посухостійкості. Було рекомендовано найбільш посухостійкі світлолюбні та тіньовитривалі види. Виявлено види, що можуть потребувати додаткового догляду під час вирощування (Phelodendron amurense та Styphnolobium japonicum), що потрібно враховувати під час озеленення міських територій.***

Висновки. ***Серед тіньовитривалих дерев для вирощування в міських умовах як високостійкі до посухи можна рекомендувати такі види: Acer mandshuricum, Acer velutinum, Corylus colurna та Prunus padus. Найбільш посухостійкими виявилися світлолюбні рослини: Liriodendron chinense, Ginkgo biloba, Acer saccharinum, Catalpa bignonioides, Catalpa fargesii та Tilia europea.***

Ключові слова: ***посухостійкість, озеленення міст, рідкісні рослини.***

Автори заявляють про відсутність конфлікту інтересів. Спонсори не брали участі в розробленні дослідження; у зборі, аналізі чи інтерпретації даних; у написанні рукопису; в рішенні про публікацію результатів.

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