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Leaf and stomatal traits of some *Magnoliaceae* plants associated with adaptation to climate aridification

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Abstract: The endurance of urban green infrastructure under ongoing climate aridification is contingent upon the selection of tree species. Plants of the family *Magnoliaceae* are a valuable resource for landscape design, but leaf structural traits associated with adaptation to water deficit remain insufficiently characterized. The aim was to determine morphometric indicators of leaves, stomata, stomatal density, and epidermal cells in plants of the genera *Liriodendron* and *Magnolia* and to identify among them species with xeromorphic leaf traits that can support plant growth and development under water-limited conditions. Eight species and two hybrids of the *Magnoliaceae* family of collection of the National Dendrological Park “Sofiyivka” of the NAS of Ukraine were examined using morphometric analysis and method of epidermal imprints. Significant interspecific variation in leaf and stomatal traits was identified, with several species demonstrating characteristics that are associated of increased tolerance to water deficit. *Magnolia kobus* is characterized by a combination of small stomata with their high density and the highest stomatal index. A similar trend is observed in *M. salicifolia*, where a high frequency of stomata is combined with their small area. *Liriodendron tulipifera* plants are distinguished by the smallest stomata, the highest epidermal cell density and the highest xeromorphic index. The study has practical implications for optimizing species composition in urban green spaces that are facing progressive climate aridification and contributes to a trait-based approach for selecting ornamental trees with potentially favorable leaf traits for water-limited conditions.

Keywords: *Liriodendron*, *Magnolia*, xeromorphic traits, stomata, urban landscaping

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Introduction

Ornamental woody plants are a key component of urban green space systems, playing an important role in meeting the aesthetic needs of the population and providing a range of ecosystem services (Kisvarga et al., 2023). Plants of the family *Magnoliaceae* Juss. represent a valuable resource for landscape design, as their large flowers of diverse colors, unusual leaves, and brightly colored fruits have attracted human attention for several centuries (Korshuk & Palagecha, 2007; Rivers et al., 2016). Early and prolonged flowering, as well as the annual abundant formation of flower buds, constitute clear advantages of magnolias in landscape plantings (Ponomarenko & Ponomarenko, 2015).

The *Magnoliaceae* family consists of two genera, *Liriodendron* L. and *Magnolia* L. (<https://powo.science.kew.org/>), which include over 300 species (Rivers et al., 2016). These are ancient relict plants that arose in the Mesozoic era during the Cretaceous and Jurassic periods (Korshuk & Palagecha, 2007; Yao et al., 2024). At that time, the natural range of *Magnoliaceae* species reached the territory of the modern Arctic but after the ice age, due to the influence of harmful natural conditions, its area significantly decreased. Currently, members of the family are concentrated in temperate and tropical regions of East and Southeast Asia, as well as the Americas. The largest centers of species diversity of *Magnoliaceae* are located in the Eastern Himalayas, Southwest China, Indochina, and other regions (Korshuk & Palagecha, 2007; Rivers et al., 2016). About half of all *Magnoliaceae* species are threatened with extinction, which is caused by habitat loss, primarily due to the intensification of logging, agriculture, and livestock farming (Rivers et al., 2016).

Climate-driven changes in hydrological cycles increase aridity and drought, and research on plant resilience and adaptability to water deficit and associated marker traits is increasingly relevant (Bertolino et al., 2019; Strashok et al., 2025; Toscano et al., 2025). These impacts are particularly pronounced in urban areas due to the urban heat island. The issue of preserving plant species diversity in residential areas is becoming increasingly important due to the rapid expansion of urbanized territories and global climate change (Marchin et al., 2022; Valliere et al., 2023; Kucheriavij et al., 2024). Minimizing the negative consequences of prolonged exposure to elevated temperatures and moisture deficiency in ecosystems is largely related to the evolutionarily formed ability of organisms to adapt to sudden changes in natural conditions. Adaptation involves phenotypic and genetic variability, reflected in physiological and morphoanatomical traits (Ivaniuta, 2020).

Sustainable urban ecosystems rely on maintaining plant diversity and selecting species adapted to environmental stress. Appropriate species selection enhances biodiversity and ecosystem services (Kisvarga et al., 2023; Toscano et al., 2025). Targeted plant selection is an effective strategy for mitigating climate change impacts (Kwiatkowski et al., 2023).

Studies on the resistance of ornamental plants to abiotic stressors remain limited (Kisvarga et al., 2023; Karagüzel, 2025). Investigating traits in arboreta and botanical garden collections that indicate stress tolerance is crucial for urban landscape diversification (Hirons et al., 2021). A valuable resource for such studies is the plant collection of the National Dendrological Park “Sofiyivka” of the NAS of Ukraine. The first records of cultivating plants of the family *Magnoliaceae* in closed soil date back to the period of the park’s foundation. The first specimens of *M. kobus* were introduced into open-ground park compositions in 1981, and *M. ×soulangeana* in 1995. In 2009, the establishment of the Magnolia Garden within the park was initiated, particularly in Hrekova Balka and the Zvirynets area (Kosenko et al., 2010). Currently, 12 species and about 40 varieties of deciduous magnolias are cultivated in the park.

Various morphological, physiological, phenological and other characteristics of plants, i.e. functional traits that reflect their growth, reproduction and survival strategies, response to changing environmental factors, influence life cycle processes, resource use, etc. (Li & Prentice, 2024). They are also essential for predicting plant responses to environmental change (Heilmeyer, 2019). Standard approaches to selecting plants based on the climatic indicators of their natural habitats are not always confirmed in modern studies, which emphasize the importance of functional traits for predicting the resilience of woody plants, especially in dynamic urban environments (Marchin et al., 2022; Levinsson et al., 2024). Numerous studies emphasize the value of physiological indicators in selecting plant species for urban landscaping aimed at creating more resilient urban environments (Esperon-Rodriguez et al., 2021). Integrating morphoanatomical, ecological, and physiological data improves understanding of plant adaptation (Imanbayeva et al., 2025).

Therefore, it is currently important to study the phenological, morphological, anatomical, physiological, and molecular genetic characteristics of plants as indicators that allow us to assess and predict their ability to adapt and maintain a high level of vitality under adverse environmental conditions, in particular water scarcity. Some researchers (Valliere et al., 2023) indicate that functional traits of leaves are a reflection of plant resistance to drought and can be indicators of the sensitivity of species to climate change, and their understanding and use will

contribute to the preservation of plant diversity in the future. Analysis of the anatomical structure of leaves allows us to identify not only their structural features but also to assess the level of adaptability to adverse environmental factors (Groza et al., 2013). To date, these aspects have not been fully studied and are the subject of ongoing research. All elements of the interconnected system of the plant organism, to which the leaf belongs, have evolved together towards the formation of strategies for efficient use of resources (Zhang et al., 2012); therefore, together they are a reflection of the adaptability of the plant organism. There are also studies that have examined leaf functional traits to understand adaptive differentiation of plant morphology under various environmental conditions (Kolesnichenko, 2015; Carlson et al., 2016), to predict plant drought resistance (Skeltson et al., 2015; Huang et al., 2020), or to determine water requirements (Badanina et al., 2024). Stomatal traits are of particular importance, as they regulate gas exchange and transpiration and reflect adaptation to environmental conditions (Šantrůček, 2022).

Given the importance of species of the family *Magnoliaceae* for both landscape design and the conservation of floristic diversity, which necessitates an understanding of their ecological behavior, particular attention should be paid to plant tolerance to water deficit when developing scientifically grounded recommendations for their use in urban landscaping.

The aim of the study was to determine leaf morphometric parameters, stomatal characteristics, stomatal density, and epidermal cell density in plants of the genera *Liriodendron* and *Magnolia*, and to identify among them species with xeromorphic leaf traits that can support plant growth and development under water-limited conditions.

Materials and methods

The objects of the study were 15–20-year-old deciduous plants of the *Magnoliaceae* family, which grow on the territory of the National Dendrological Park “Sofiyivka” of the NAS of Ukraine: *Liriodendron tulipifera* L., *Magnolia cylindrica* E.H. Wilson, *Magnolia denudata* Desr., *Magnolia ×kewensis* Pearce, *Magnolia kobus* DC., *Magnolia liliiflora* Desr., *Magnolia officinalis* Rehd. & E.H. Wilson, *Magnolia salicifolia* (Siebold & Zucc.) Maxim., *Magnolia ×soulangeana* Soul.-Bod., *Magnolia stellata* (Siebold & Zucc.) Maxim.

The study of the morpho-anatomical characteristics of leaves was carried out on morphologically mature leaves selected from the southern side of the middle part of the plant crown to ensure uniform sampling conditions and to minimize variability caused by differences in light exposure within the crown. For each species, 25 leaves were sampled. The

length, width and area of the leaf blade were determined. The leaf weight method was used to determine the area (Kaushik et al., 2021). The leaf impression technique using nail varnish was applied for the study of the stomata apparatus (Wu & Zhao, 2017). The impressions were observed under the Levenhuk MED 25T microscope at magnifications of $\times 100$ and $\times 400$, and high-resolution images were captured using a 5.1 MP digital camera. Measurements were performed using LevenchukLite software.

The subsequent quantitative indicators were assessed: the guard cell and stomatal slit's length and width, the stomata's area, and the density of stomata and epidermal cells per unit area of the abaxial surface of the leaves. Based on these parameters, the stomatal index and xeromorphy index were calculated. All measurements were performed with 25 replicates. The stomatal area was calculated as the product of stomatal length and width multiplied by a proportionality coefficient (0.8071) established for plants of the family *Magnoliaceae* (Yan et al., 2025). The stomatal index (SI) was calculated using the formula:

$$SI = Kn \times 100 / (Ke + Kn)$$

where SI is the stomatal index; Kn is the number of stomata per 1 mm² of the abaxial leaf surface; and Ke is the number of epidermal cells, including subsidiary cells, within the same area. The xeromorphy index (Ixr) was calculated using the formula:

$$Ixr = (Ne + Nn) / 100$$

where Ne is the density of epidermal cells per 1 mm² and Nn is the stomatal density per 1 mm² (Kryvoruchko & Bessonova, 2018). The stomatal index and xeromorphy index were used to determine the level of drought resistance of plants: the higher they are, the higher the drought resistance of plants.

Statistical analysis of the research results included the determination of minimum (min), maximum (max), mean ($\bar{x}$) values, and standard error (SE). Differences among species were evaluated using one-way analysis of variance (ANOVA), with species treated as the fixed factor. When significant differences were detected, means were compared using Tukey's (HSD) test. Differences with $p < 0.05$ were considered significant.

Results

The leaves of *Magnoliaceae* plants are alternate, usually entire, rarely lobed (in plants of the genus *Liriodendron*), with large stipules. In plants of the genus *Liriodendron*, the leaves are large, 2–6-lobed,

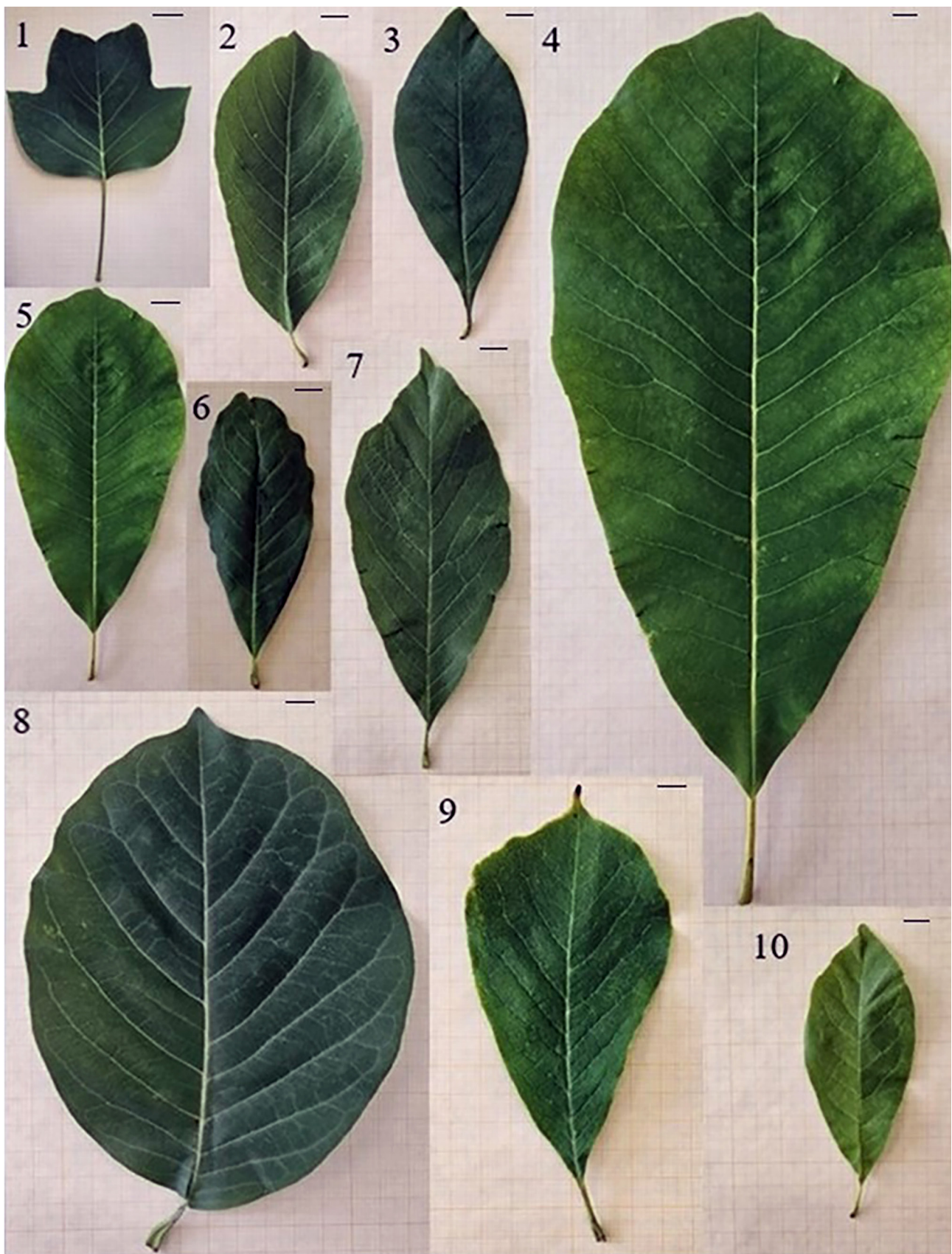


Fig. 1. Leaves of Magnoliaceae species: 1 – *L. tulipifera*, 2 – *M. cylindrica*, 3 – *M. liliiflora*, 4 – *M. officinalis*, 5 – *M. ×kewensis*, 6 – *M. stellata*, 7 – *M. kobus*, 8 – *M. denudata*, 9 – *M. ×soulangeana*, 10 – *M. salicifolia* (scale bar 1 cm)

with long petioles and deciduous stipules (Tsybrovska, 2019). The leaves of the studied species of the genus *Magnolia* are species are entire, bilaterally symmetrical, and glabrous at maturity; young leaves are pubescent, with trichomes later restricted to veins.

Morphometric leaf traits of the studied plants of the family *Magnoliaceae* are presented in Figures 1, 2 and Table 1. One-way ANOVA demonstrated significant interspecific differences for all analyzed traits (Table 2). The lowest leaf width was recorded

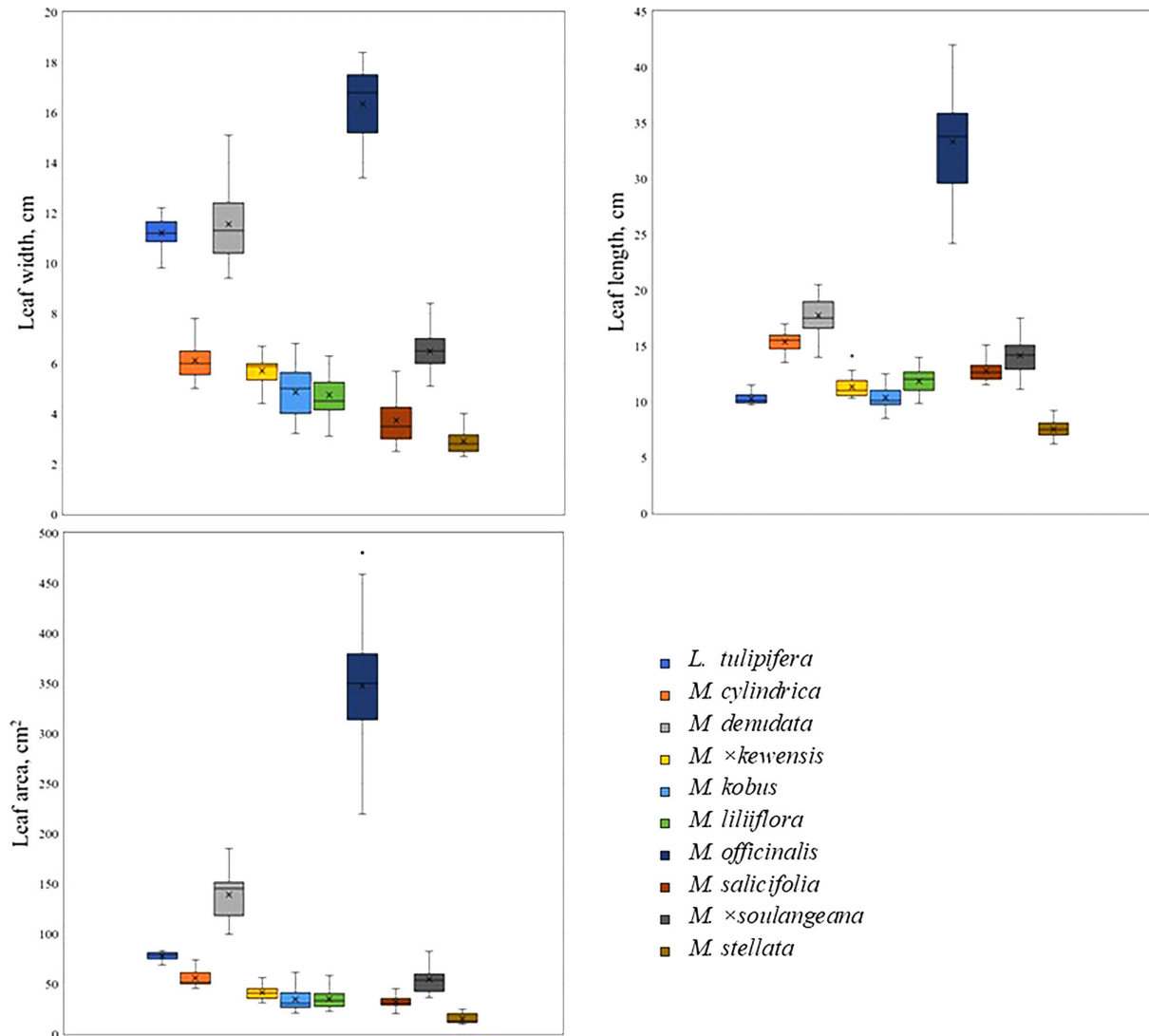


Fig. 2. Boxplots illustrating variation in biometric parameters of leaves of *Magnoliaceae* plants

Table 1. Biometric parameters of leaves of plants of the family *Magnoliaceae* (n=25, $\bar{x} \pm SE$)

Species	Width, cm		Length, cm		Leaf area, cm ²	
	min-max	$\bar{x} \pm SE$	min-max	$\bar{x} \pm SE$	min-max	$\bar{x} \pm SE$
<i>L. tulipifera</i>	9.8–12.2	11.2±0.12a	9.7–11.5	10.2±0.10c	68.5–83.5	77.7±0.90c
<i>M. cylindrica</i>	5.0–7.8	6.1±0.16cf	13.9–17.0	15.4±0.18d	45.7–74.1	55.6±1.69dc
<i>M. denudata</i>	9.4–15.1	11.5±0.32a	14.0–20.5	17.7±1.32a	99.5–165.5	138.9±4.76a
<i>M. ×kewensis</i>	4.4–6.7	5.7±0.12cf	10.3–14.1	11.3±0.18c	33.2–56.4	41.1±1.32cdf
<i>M. kobus</i>	3.7–6.8	4.9±0.21cd	8.8–12.5	10.4±0.20c	20.5–61.6	34.3±2.18cdf
<i>M. liliiflora</i>	3.1–6.3	4.7±0.16cd	9.8–14.0	11.8±0.22cf	22.5–58.2	34.8±1.87edf
<i>M. officinalis</i>	13.4–18.4	16.3±0.29b	24.2–42.9	33.3±0.90b	219.3–519.1	347.1±15.22b
<i>M. salicifolia</i>	2.5–5.7	3.7±0.18de	11.5–15.1	12.8±0.19c	20.0–45.1	31.4±1.22df
<i>M. ×soulangeana</i>	5.2–8.4	6.5±0.16f	11.1–17.5	14.1±0.34df	36.4–82.3	54.4±2.53d
<i>M. stellata</i>	2.3–4.0	2.9±0.10e	6.2–9.2	7.5±0.15e	9.6–24.7	15.0±0.90f
$\bar{x}$	–	7.4	–	14.5	–	83.0

Note: the different letters indicate statistically significant differences in the means of the compared pair according to the Tukey test.

in *M. stellata* (2.9 cm), whereas the highest value was observed in *M. officinalis* (16.3 cm). Regarding leaf length, the minimum values were recorded in *M. stellata* (7.5 cm), while the maximum values

Table 2. One-way ANOVA results for leaf morphometric traits

Trait	SS	df	MS	F value	P value
Leaf width	4096.156	9	455.128	484.002	< 0.0001
Leaf length	11725.069	9	1302.785	418.099	< 0.0001
Leaf area	2208979.010	9	245442.112	339.910	< 0.0001

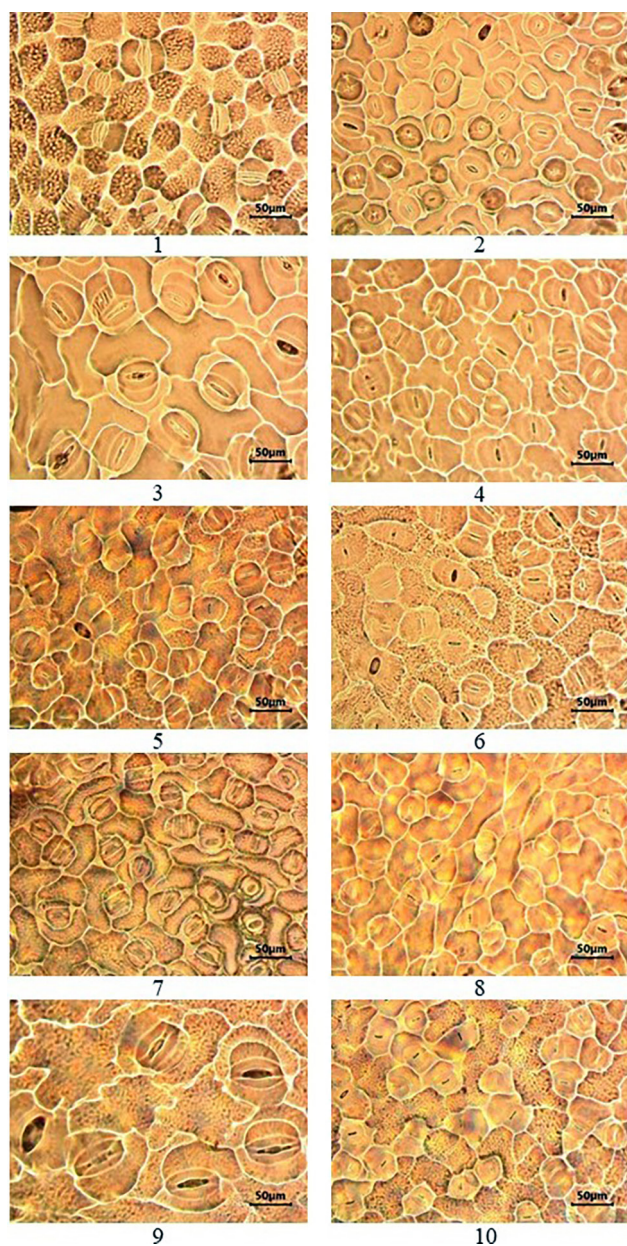


Fig. 3. Stomatal apparatus on abaxial leaf epidermal impressions of *Magnoliaceae* species: 1 – *L. tulipifera*, 2 – *M. cylindrica*, 3 – *M. denudata*, 4 – *M. ×kewensis*, 5 – *M. kobus*, 6 – *M. liliiflora*, 7 – *M. officinalis*, 8 – *M. salicifolia*, 9 – *M. ×soulangeana*, 10 – *M. stellata*

were observed in *M. officinalis* (33.3 cm). The leaf area of the studied plants of the family *Magnoliaceae* was 83.3 cm², with the smallest value observed in *M. stellata* (15.0 cm²). *M. officinalis*, across all measured parameters, formed a separate group with the highest values of leaf width, length, and area. *M. stellata* constituted a distinct statistical group characterized by the lowest leaf width and length values.

On epidermal impressions of the abaxial leaf surface of plants of the family *Magnoliaceae*, clearly visible paracytic stomata and the boundaries of epidermal cells were observed (Fig. 3).

The morphometric characteristics of the stomatal apparatus of *Magnoliaceae* species comprised guard cell length and width, stomatal pore length and width, and stomatal area (Table 3, Fig. 4). One-way ANOVA revealed significant interspecific differences for all measured stomatal traits (Table 4).

The length of guard cells in the studied plant species ranged from 24.9 to 59.6 µm. The highest values were recorded in *M. ×soulangeana* and *M. denudata*, amounting to 59.6 and 50.2 µm, respectively. The smallest guard cell lengths were observed in *M. kobus* and *L. tulipifera*, with values of 24.9 and 28.3 µm, respectively. The width of the guard cells of the stomata varied within 6.4–13.5 µm and was maximum in plants *M. ×soulangeana* and minimum in *L. tulipifera*. According to the linear parameters of the stomatal apparatus (guard cell length and width, stomatal pore length and width), several statistically distinct groups were identified. Species with the largest values of these indicators, in particular *M. ×soulangeana* and *M. denudata*, were significantly different from species with small linear dimensions, such as *M. kobus* and *L. tulipifera*.

The stomatal area varied within a wide range from 288.2–475.7 µm² in *L. tulipifera* to 1321.7–2362.2 µm² in *M. ×soulangeana*, which is associated with significant morpho-anatomical differences in the stomatal apparatus among species. Species with the largest stomatal area (*M. ×soulangeana*, as well as *M. denudata* and *M. stellata*) differed significantly from species with comparatively smaller stomatal area (*L. tulipifera*, *M. kobus*, *M. officinalis*).

Significant interspecific differences in stomatal density and epidermal cell density among the studied plants of the *Magnoliaceae* family were confirmed by one-way analysis of variance (Table 5), and their values are presented in Figure 5.

Stomatal density on the abaxial leaf surface varied considerably among the studied taxa, ranging from 67.1 to 268.5 stomata/mm². The highest stomatal density was observed in *M. cylindrica*, *M. kobus*, *M. officinalis* (more than 250.0 stomata/mm²). Relatively low stomatal density was observed in *M. ×soulangeana* (67.1 stomata/mm²), *L. tulipifera* (96.1 stomata/mm²), *M. denudata* (99.8 stomata/mm²), and

M. liliiflora (160.1 stomata/mm²), which differed significantly from the other studied objects. The remaining species predominantly formed statistically homogeneous groups.

In the studied plants, the epidermal cell density on the leaf surface ranged from 67.1 to 268.5 cells/

mm². *L. tulipifera* was characterized by a high epidermal cell density (706.3 cells/mm²), whereas *M. ×soulangeana* had a low value (151.5 cells/mm²). Statistically significant interspecific differences in epidermal cell density were observed in *L. tulipifera*, *M. cylindrica*, *M. denudata*, and *M. ×soulangeana*.

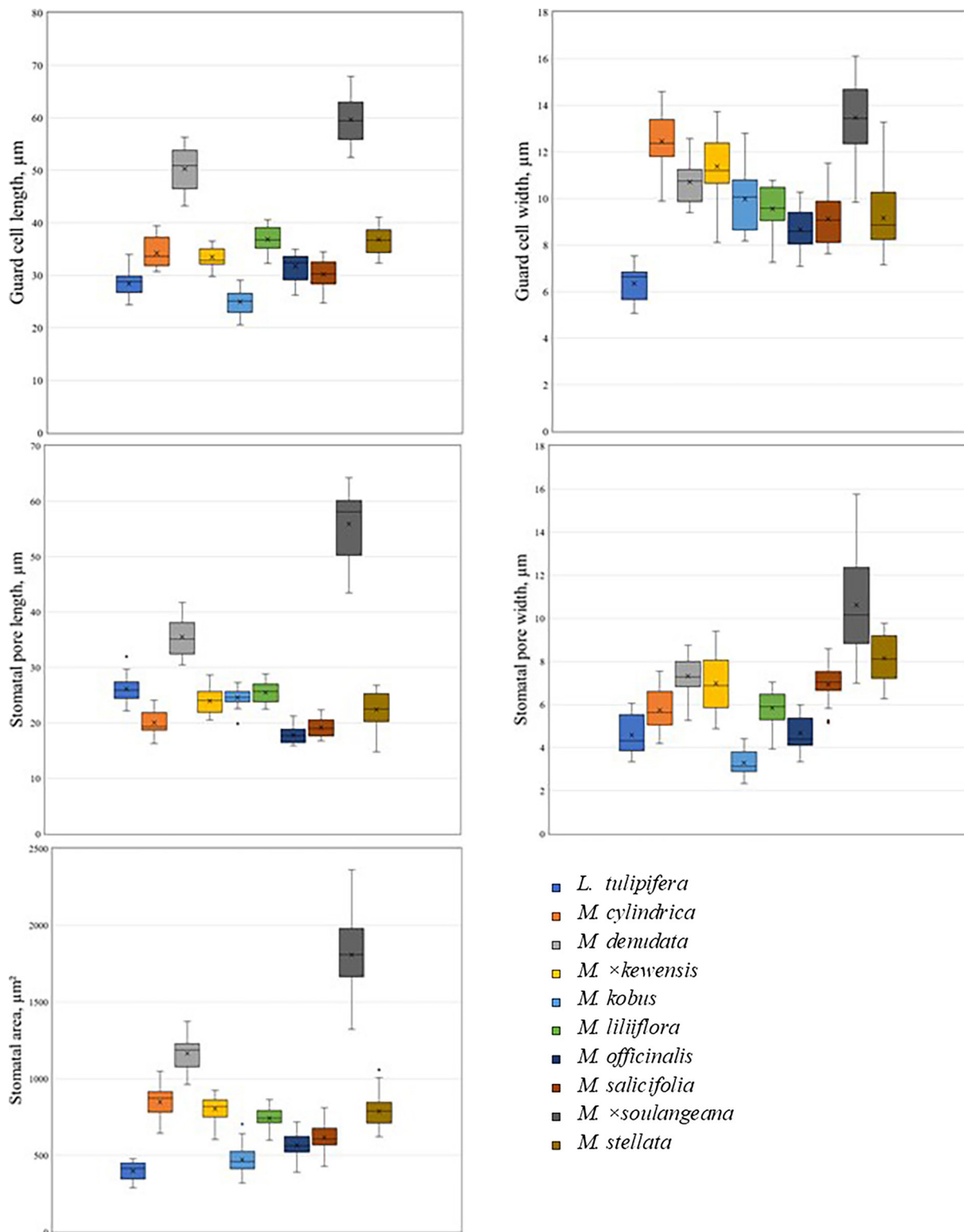


Fig. 4. Boxplots illustrating variation in biometric parameters of the stomatal apparatus of Magnoliaceae plants

Table 3. Biometric parameters of the stomatal apparatus of *Magnoliaceae* species (n=25, $\bar{x} \pm SE$)

Species	Guard cell length, μm		Guard cell width, μm		Stomatal pore length, μm		Stomatal pore width, μm		Stomatal area, μm^2	
	min-max	$\bar{x} \pm SE$	min-max	$\bar{x} \pm SE$	min-max	$\bar{x} \pm SE$	min-max	$\bar{x} \pm SE$	min-max	$\bar{x} \pm SE$
<i>L. tulipifera</i>	24.4–33.9	28.3 $\pm$ 0.50cd	5.1–6.3	6.3 $\pm$ 0.15a	22.2–31.9	26.2 $\pm$ 0.45c	3.3–6.1	4.8 $\pm$ 0.18a	288.2–475.7	397.1 $\pm$ 11.57d
<i>M. cylindrica</i>	30.7–39.4	34.2 $\pm$ 0.56fg	9.9–14.6	12.5 $\pm$ 0.24bf	16.3–24.1	20.1 $\pm$ 0.45de	4.2–7.5	5.7 $\pm$ 0.18ab	644.4–1048.7	846.2 $\pm$ 19.44c
<i>M. denudata</i>	43.2–56.3	50.2 $\pm$ 0.82a	9.4–12.6	10.7 $\pm$ 0.18c	30.5–41.7	35.5 $\pm$ 0.66a	5.3–8.8	7.3 $\pm$ 0.17bd	960.6–1373.4	1163.7 $\pm$ 22.83a
<i>M. $\times$kewensis</i>	29.8–36.5	33.5 $\pm$ 0.37fg	8.1–13.7	11.4 $\pm$ 0.26bd	20.5–28.6	24.0 $\pm$ 0.46c	4.9–9.4	6.98 $\pm$ 0.26b	603.4–922.5	802.5 $\pm$ 17.19c
<i>M. kobus</i>	20.5–29.1	24.9 $\pm$ 0.44bc	8.8–12.8	10.0 $\pm$ 0.26cdg	19.8–27.3	24.6 $\pm$ 0.32c	2.3–4.4	3.3 $\pm$ 0.11a	318.8–704.0	471.2 $\pm$ 19.31bdf
<i>M. liliiflora</i>	32.3–40.6	36.9 $\pm$ 0.50fg	7.3–10.8	9.6 $\pm$ 0.19eg	22.5–28.9	25.5 $\pm$ 0.39c	3.9–7.0	5.8 $\pm$ 0.17ab	597.9–862.7	741.3 $\pm$ 14.89bc
<i>M. officinalis</i>	26.2–35.0	31.7 $\pm$ 0.48df	7.1–10.3	8.7 $\pm$ 0.18fg	15.9–21.2	17.8 $\pm$ 0.30d	3.3–6.0	4.7 $\pm$ 0.15a	390.0–717.0	634.2 $\pm$ 15.29f
<i>M. salicifolia</i>	24.7–34.5	30.2 $\pm$ 0.54df	7.6–11.5	9.1 $\pm$ 0.22cg	16.8–22.4	19.2 $\pm$ 0.32de	5.2–8.6	6.9 $\pm$ 0.16b	428.2–810.8	685.1 $\pm$ 19.12bf
<i>M. $\times$soulangiana</i>	52.5–67.9	59.6 $\pm$ 0.84e	9.8–16.1	13.5 $\pm$ 0.31f	43.5–64.3	55.9 $\pm$ 1.34b	7.0–15.8	10.6 $\pm$ 0.47c	1321.7–2362.2	1807.0 $\pm$ 48.50e
<i>M. stellata</i>	32.3–41.1	36.8 $\pm$ 0.52g	8.2–10.2	9.2 $\pm$ 0.29cg	14.8–26.8	22.4 $\pm$ 0.64e	6.3–9.8	8.2 $\pm$ 0.22bd	620.3–1056.0	786.9 $\pm$ 23.01c
$\bar{x}$	–	36.6	–	10.1	–	27.1	–	6.4	–	819.6

Note: the different letters indicate statistically significant differences in the means of the compared pair according to the Tukey test.

Table 4. One-way ANOVA results for biometric parameters of the stomatal apparatus

Trait	SS	df	MS	F value	P value
Guard cell length	25017.309	9	2779.701	335.079	< 0.0001
Guard cell width	928.865	9	103.207	76.962	< 0.0001
Stomatal pore length	28554.656	9	3172.739	342.897	< 0.0001
Stomatal pore width	974.332	9	108.259	83.195	< 0.0001
Stomatal area	37705456.630	9	4189495.181	310.093	< 0.0001

Table 5. One-way ANOVA results for stomatal and epidermal cell density

Trait	SS	df	MS	F value	P value
Stomatal density	860380.0493	9	95597.7833	232.2728	< 0.0001
Epidermal cell density	3327050.8615	9	369672.3179	383.2260	< 0.0001

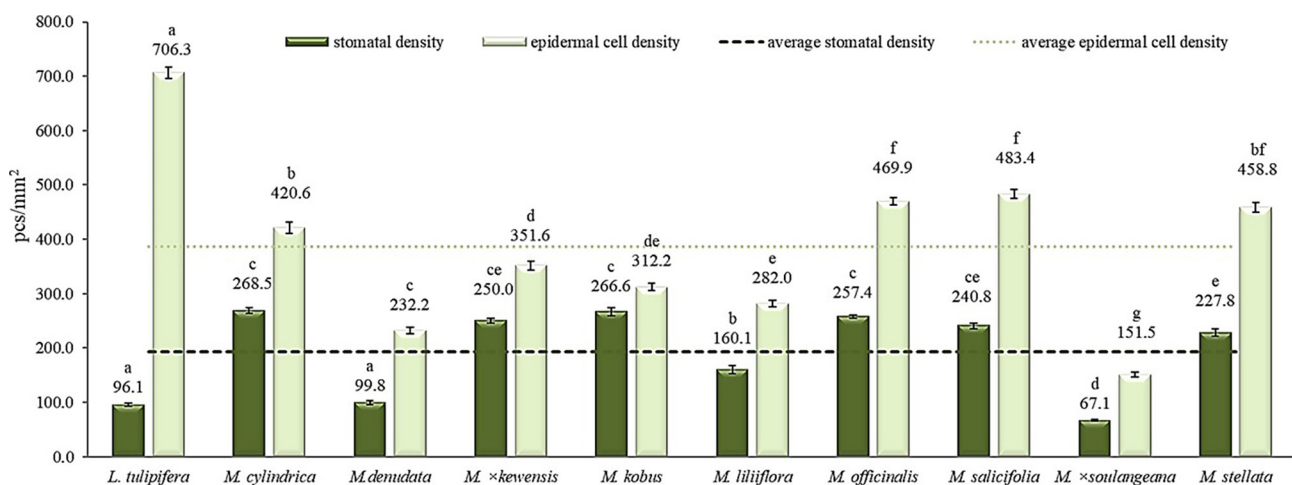
Fig. 5. Stomatal and epidermal cell density on the abaxial leaf surface of plants of the family *Magnoliaceae* (n=25, $\bar{x} \pm SE$)

Table 6. One-way ANOVA results for stomatal index and xeromorphy index

Trait	SS	df	MS	F value	P value
Stomatal index	11211.8354	9	1245.7595	158.2415	< 0.0001
Xeromorphy index	489.9769	9	54.4419	340.4689	< 0.0001

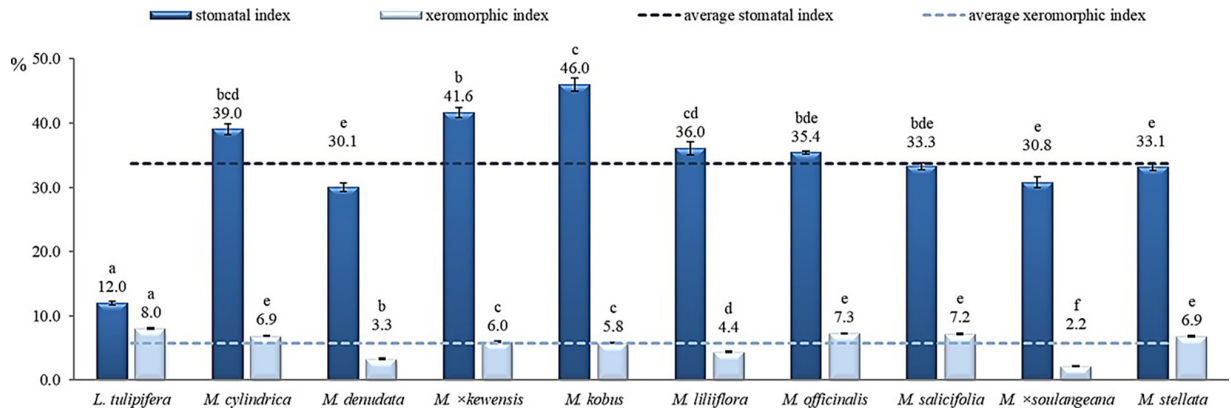


Fig. 6. Stomatal index and xeromorphy index of plants of the family Magnoliaceae (n=25, $\bar{x} \pm SE$)

Significant interspecific differences were found in the stomatal index and xeromorphy index (Table 6). The stomatal index ranged from 12.0% to 46.0% (Fig. 6). *L. tulipifera* showed the lowest stomatal index, whereas the other species formed statistically homogeneous groups for this parameter. The xeromorphy index ranged from 2.2% to 8.0% (Fig. 6). *L. tulipifera* exhibited the highest values of this index, whereas *M. xsoulangiana* and *M. denudata* showed the lowest values, with differences that were statistically significant compared to all studied species.

The results demonstrate pronounced interspecific variability in leaf morphometric and stomatal traits of Magnoliaceae, reflecting different adaptation strategies to water deficit. *L. tulipifera* showed the smallest stomata area (397.1 μm^2), a low stomata density (96.1 stomata/mm²), and the highest xeromorphic index (8.0%). A similar tendency were observed in *M. kobus*, characterized by the smallest dimensions of the stomatal apparatus components (guard cell length – 24.9 μm , guard cell width – 10.0 μm , stomatal area – 471.2 μm^2), a high density of their distribution on the leaf blade (266.6 stomata/mm²), and the highest stomatal index (46.0%). *M. salicifolia* and *M. officinalis* also exhibited relatively small stomata (615.1 and 564.7 μm^2) and high density (240.8 and 257.4 stomata/mm²). Smaller leaf area in *M. salicifolia* and *M. kobus* suggests lower water demand. In contrast, *M. xsoulangiana* showed weak xeromorphic traits, with the lowest stomatal density (67.1 stomata/mm²), largest stomata (1807.0 μm^2), and lowest xeromorphic index (2.2%). *M. officinalis* had the largest leaves, indicating higher water consumption. Less pronounced xeromorphic traits were also observed in *M. denudata*, characterized by large stomatal areas (1163.7 μm^2) and low values of the xeromorphic index (3.3%).

Discussion

The results of our study demonstrate pronounced interspecific variability in morphometric and stomatal traits of leaves of representatives of the Magnoliaceae family under cultivation conditions in the National Dendrological Park “Sofiyivka” of the NAS of Ukraine. We found a diversity of structural organization of leaves of eight species and two hybrids, in particular differences in leaf size, stomatal size and density, epidermal cell density, stomatal index, and xeromorphy index, which scientists consider as potential marker traits associated with adaptation to water deficit (Lawson et al., 2014; Villaseñor & Terrazas, 2017; Huang et al., 2020; Badry et al., 2024).

According to the criterion of leaf blade size, *M. stellata* plants were distinguished among the studied objects by having the smallest leaves (15.0 cm²), which may indicate a more efficient water-use strategy under conditions of limited water availability. Small leaf area was also characteristic of *M. salicifolia*, *M. liliiflora*, and *M. kobus*. In contrast, *M. officinalis* plants were distinguished by the largest leaves (347.1 cm²), which is typically associated with higher water consumption required to sustain vital processes (Tabassum et al., 2021; Roth-Nebelsick & Krause, 2023). Leaf size is closely related to resource-use efficiency, particularly water loss and carbon gain. Smaller leaves generally reduce transpiration and show higher drought resistance due to improved hydraulic efficiency and vein density (Kramp et al., 2022; Roth-Nebelsick & Krause, 2023).

The smallest stomata in area are characteristic of *L. tulipifera* and *M. kobus* plants (397.1 and 471.2 μm^2 , respectively), which may indicate the potentially high efficiency of water use by this species in drought conditions. Stomata regulate gas exchange and

transpiration and respond dynamically to environmental conditions. Plants adapt to environmental changes by regulating transpiration and CO₂ uptake through dynamic stomatal control and adjustment of stomatal traits (Hou et al., 2024). Smaller stomata tend to have faster opening and closing kinetics, which clearly provides more efficient regulation of transpiration and gas exchange under conditions of fluctuating water availability (Drake et al., 2013; Lawson & Vialet-Chabrand, 2019). Not only their size but also their density is closely related to photosynthetic activity and water use efficiency, making them key indicators of plant ecological performance (Xu & Zhou, 2008; Chua & Lau, 2024). An inverse relationship between stomatal density and atmospheric CO₂ concentration has been reported, reflecting an adaptive strategy to optimize water-use efficiency. Stomatal density is widely recognized as a key indicator of plant resilience, particularly under water deficit conditions (Groza et al., 2013). However, despite their similar small stomata, these species differed significantly in their density. *L. tulipifera* together with *M. ×soulangeana* and *M. denudata* (less than 100.0 stomata/mm²) were characterized by low stomatal density, while *M. kobus*, and *M. cylindrica* and *M. officinalis*, had the highest values for this parameter (more than 250.0 stomata/mm²). This disparity may suggest that these species employ distinct structural strategies to regulate water loss. Reducing stomatal density is associated with lower transpiration and improved water use efficiency, especially in agricultural crops, and is therefore regarded as a promising strategy to increase their drought tolerance (Franks et al., 2015; Yang et al., 2026). However, comparative studies confirm that smaller and more numerous stomata are associated with higher responsiveness and improved water-use efficiency under arid conditions (Johnson et al., 2011; Drake et al., 2013; Kolesnichenko, 2015; Carlson et al., 2016; Durand et al., 2019). Therefore, stomatal density should not be considered in isolation, but rather in combination with stomatal size and other anatomical and physiological traits that are related to water use efficiency and plant drought tolerance. Although stomatal size and density are widely used as indicators of plant response, the mechanisms underlying stomatal regulation remain insufficiently understood (Lawson & Vialet-Chabrand, 2019).

According to the results of research conducted in Romania, the stomatal density of *M. kobus* plants was almost five times higher than that of the hybrid *M. ×soulangeana* (Groza et al., 2013). The stomatal density in *M. kobus* was found to be twice as high as in *M. denudata*, which is consistent with the results reported by Badanina et al. (2024). Species with large stomata and low density are generally less tolerant to drought conditions (Krugliak, 2018). Our

research data indicate the lowest level of xeromorphism in *M. ×soulangeana* plants, which is based on the lowest stomatal density (67.1 stomata/mm²) and their largest size (1807.0 µm²).

L. tulipifera was characterized by a high epidermal cell density (706.3 cells/mm²), which is one of the anatomical features and structural modifications of plants that researchers associate with increased water use efficiency. Increased epidermal cell density has often been observed under drought stress (Kofidis et al., 2004; Cordovilla et al., 2025). *M. ×soulangeana* showed the lowest epidermal cell density among the taxa studied (151.5 cells/mm²). Given the low stomatal density and large stomatal size, *M. ×soulangeana* plants displayed less pronounced xeromorphic leaf characteristics.

In this study, *M. ×soulangeana* also exhibited the lowest xeromorphic index (2.2%), confirming its low drought tolerance, consistent with previous reports (Vastag et al., 2020). *Liriodendron tulipifera* combined low stomatal index (8.0%) with a high xeromorphic index (12.0%), suggesting that drought tolerance cannot be explained by a single parameter but requires an integrated assessment of multiple traits. In contrast, *M. kobus* showed the highest stomatal index (46.0%) together with small stomata (guard cell length 24.9 µm, width 10.0 µm) and high stomatal density (266.6 stomata/mm²), indicating pronounced xeromorphic features.

Stomatal and epidermal cell density, as well as guard cell size, vary depending on environmental conditions, whereas the stomatal index is generally considered a relatively stable species-specific trait and is therefore used in taxonomic studies (Pompelli et al., 2010; Badry et al., 2024). Variability of this indicator was observed in plants of the genus *Quercus* L. and *Forsythia europaea* Degen & Bald., depending on the technogenic load and the characteristics of the location of trees in the structure of green spaces (Kryvoruchko & Bessonova, 2018; Lescheniuk & Mazura, 2021; Leshcheniuk & Koniakin, 2022).

In previous studies, drought tolerance of *Magno-liaceae* was assessed using various methodological approaches, including species distribution modeling, physiological measurements, photosynthetic performance, and biochemical indices.

A prediction system based on species distribution and climatic variables was recently presented to assess the potential drought tolerance of Chinese *Mag-nolia* species. None of the species presented in our study were classified as drought tolerant in the study by Gou et al. (2025). Drought tolerant species included *M. albosericea* Chun & C.H.Tsoong, *M. biondii* Pamp., *M. campbellii* Hook.f. & Thomson, *M. delavayi* Franch., *M. globosa* Hook.f. & Thomson, *M. laevifolia* (Y.W.Law & Y.F.Wu) Noot., *M. nitida* W.W.Sm., *M. sargentiana* Rehder & E.H.Wilson and *M. wilsonii*

(Finet & Gagnep.) Rehder. Instead, *M. cylindrica*, *M. denudata*, and *M. liliiflora* were identified as having low drought tolerance, with *M. cylindrica* being the least drought tolerant of them, followed by *M. denudata* and *M. liliiflora*. This pattern is generally consistent with our findings, as these species did not exhibit a combination of leaf morphometric and stomatal traits commonly associated with potential tolerance to water-deficit conditions.

Drought tolerance of *Magnolias* has also been assessed using physiological parameters. Sjöman et al. (2018) compared seven magnolia species based on leaf turgor loss point and reported similar drought tolerance in *M. kobus* and *M. salicifolia*, while *M. tripetala* (L.) L. and *M. virginiana* L. showed greater drought tolerance.

Similar results were obtained by Vastag et al. (2020), who compared the physiological responses of *M. grandiflora* L. and *M. ×soulangeana* to drought stress in an urban environment. They demonstrated that *M. grandiflora* maintained higher photosynthetic productivity under water deficit conditions, while *M. ×soulangeana* was significantly more sensitive to drought. Our results support these observations, as *M. ×soulangeana* exhibited the largest stomata, the lowest stomatal density, the lowest epidermal cell density, and the lowest xeromorphic index among the studied plants, indicating less pronounced xeromorphic leaf characteristics.

Overall, the available data suggest that drought tolerance in *Magnoliaceae* plants can't be determined based on a single trait or methodological approach. Instead, the integration of anatomical, physiological, and ecological data is essential for understanding species-specific adaptive strategies. In this context, comparative analysis of morphometric and stomatal leaf characteristics provides an important additional perspective for assessing the adaptive potential of magnolias under conditions of increasing climate aridification.

Given the considerable taxonomic diversity of the *Magnoliaceae* family, physiological studies have so far been conducted for only a limited number of species. Therefore, comparative studies of additional taxa remain important to identify general patterns of structural and functional adaptation to water scarcity. However, it should be noted that confirmation of drought tolerance requires further experimental evaluation under controlled or field drought conditions.

Conclusion

Based on a comprehensive morphological and anatomical study of leaves of various species of the *Magnoliaceae* family cultivated in the National Dendrological Park "Sofiyivka" of the NAS of Ukraine,

species-specific differences in individual characteristics were established, including leaf blade size, stomatal parameters, density of their location, stomatal index, and xeromorphic index, which may serve as potential indicators associated with plant responses to water deficit and climate aridification.

The leaf area varies in a wide range (9.6–519.1 cm²) and is characterized by the smallest values in *M. stellata*, *M. salicifolia*, *M. kobus*, and *M. liliiflora*, which may reflect structural adaptations potentially associated with drought resistance.

Pronounced xeromorphic traits of the stomatal apparatus were found in *M. kobus* and *M. salicifolia*, which may indicate their potential tolerance to moisture deficiency. *M. kobus* plants are characterized by a combination of small stomata (471.2 μm²) with a high density of their location (266.6 stomata/mm²) and the highest stomatal index (46.0%). A similar trend is observed in *M. salicifolia*, where a high stomatal density (240.8 stomata/mm²) is combined with their small area (615.1 μm²). Despite the low stomatal density (96.1 stomata/mm²), *Liriodendron tulipifera* plants are distinguished by the smallest stomatal area (397.1 μm²), the highest epidermal cell density (706.3 cells/mm²) and the highest xeromorphic index (8.0%), indicating a combination of structural traits potentially associated with efficient water use under drought conditions.

The low level of manifestation of xeromorphic features (the lowest stomatal density is 67.1–99.8 stomata/mm², their largest sizes are 1807.0–1163.7 μm², and the low xeromorphic index is 2.2–3.3%) in *M. ×soulangeana* and *M. denudata* plants may be associated with high water consumption to ensure vital processes, which makes them unsuitable for widespread use in landscaping under conditions of insufficient moisture.

Given global climate change and increasing aridity of urbanized areas, the use of scientifically based methods for selecting plant assortments for landscaping is crucial in creating sustainable urban ecosystems. The complex of xeromorphic leaf traits identified in *M. kobus*, *L. tulipifera*, and *M. salicifolia* suggests that these species may be considered in future scientifically based tree selection for urban landscaping under conditions of increasing aridity. However, confirmation of drought tolerance of individual species requires further experimental evaluation under controlled or field drought conditions.

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