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# THE IMPACT OF AIR TEMPERATURE ON THE SUSTAINABILITY OF *TRACHELOSPERMUM JASMINOIDES* (LINDL.) LEM. UNDER CONDITIONS OF A TEMPERATE CONTINENTAL CLIMATE

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**Abstract**

Star Jasmine (*Trachelospermum jasminoides* (Lindl.) Lem.) is an economically important commercial species for to its ornamental and ecological benefits. Therefore, responses to variations in air temperature are significant for its sustainability and shifts in phenophases, which can have long-term effects on its distribution, functions, and ecosystem services. An integrative approach to phenological patterns using the BBCH scale and biometric traits in the study, along with the analysis of trends and correlations, is a key step in obtaining valuable information for the management and conservation of Star Jasmine. The findings of intensive research in Serbia over three consecutive years stand out due to crucial information about the morphological features of leaves, inflorescences, flowers, and the species' acclimatization. The obtained results confirm the temporally consistent phenological patterns of leafing, but a 57-day earlier onset and a 26-day longer full flowering phenophase, influenced by high air temperatures in the globally hottest year, 2024. Additionally, it was observed that Star Jasmine tolerates frosts down to -15.5°C and multiple consecutive frost days, under conditions of a temperate continental climate at altitudes up to 200m. The results are important for complementing the list of suitable plants for nature-based landscape design, attractive to birds, bees, butterflies, and other organisms displaced due to rapid urban development and play a vital role in ecosystem services, as they help regulate harmful insect populations and support pollination. Our study confirms that seasonal changes in Star Jasmine are influenced by fluctuating air temperatures, a trend that must be continued in the coming years to highlight the impact of climate change on urban landscape phenology and species sustainability.

**Key words:** Star Jasmine; Acclimatization; Phenology; Biometric attributes; Residual values

## Introduction

The worldwide climate change research, particularly about temperature variations, confirm trend of increasing air temperatures since the second half of the nineteenth century, with more intense warming from 1920 to 1944, after 1975 (Rebetez & Reinhard, 2008), and especially since 2015 (Anon., 2021, Ocokoljić *et al*., 2023). Responses to air temperature variations are shifts in phenophases over time, and these shifts may have long-term effects on species distribution, ecosystem functions, and services (Parmesan, 2006, Crimmins *et al*., 2010, Richardson *et al*., 2010). This is particularly relevant for flowering of ornamental taxa, such as *Trachelospermum jasminoides* (Lindl.) Lem. (*THJA*), which has been widely introduced into the horticultural market (Wellington, 2017). The timing of reproductive phenophases is crucial for this species as it can influence the strength of interactions between plants and their pollinators (Forrest, 2015).

*THJA* belongs to the family *Apocynaceae* Juss., which includes around 400 genera and 4,555 species, primarily distributed in tropical to warm temperate regions (Stevens, 2012), and the genus *Trachelospermum* Lem. with 15 species according to the Flora of China Editorial Committee (2017) and 10 species according to POWO (2025), consisting of woody climbers, one of which is native to North America, while the others are native to Asia (Flora of China Editorial Committee, 2017). The botanical and common names of *THJA* (Asiatic jasmine, Chinese star jasmine, Confederate jasmine, Japanese star jasmine, Small leaf confederate jasmine, Star jasmine) reflect its fragrant flowers, which resemble those of jasmine (Rojas-Sandoval, 2022). *THJA* is a light and partial shade species and in its native populations grows in well-drained soils (pH ranging from 4.5 to 8) on forest edges, thickets, disturbed habitats, and along roads and paths at altitudes between 200 and 1,300 meters (Flora of China Editorial Committee, 2017). Owing its fast growth, it colonizes areas even when not fruiting, as it spreads vegetatively and poses a potential threat to biodiversity (Gilman, 1999; Clifford & Kobaiashi, 2010), though as an invasive species, it has only been recorded in the Bahamas (Anon., 2025). In landscape design, it is an element of gardens, parks, recreational areas, and other open spaces (Gilman, 1999; TGA Australia, 2017) as a ground cover and in vertical greening of landscape architectural structures, serving functions such as creating shade, fostering contact with nature, providing aesthetic value, supporting education, filtering air pollution, and providing habitat for birds and insects (Hansen, 2010).

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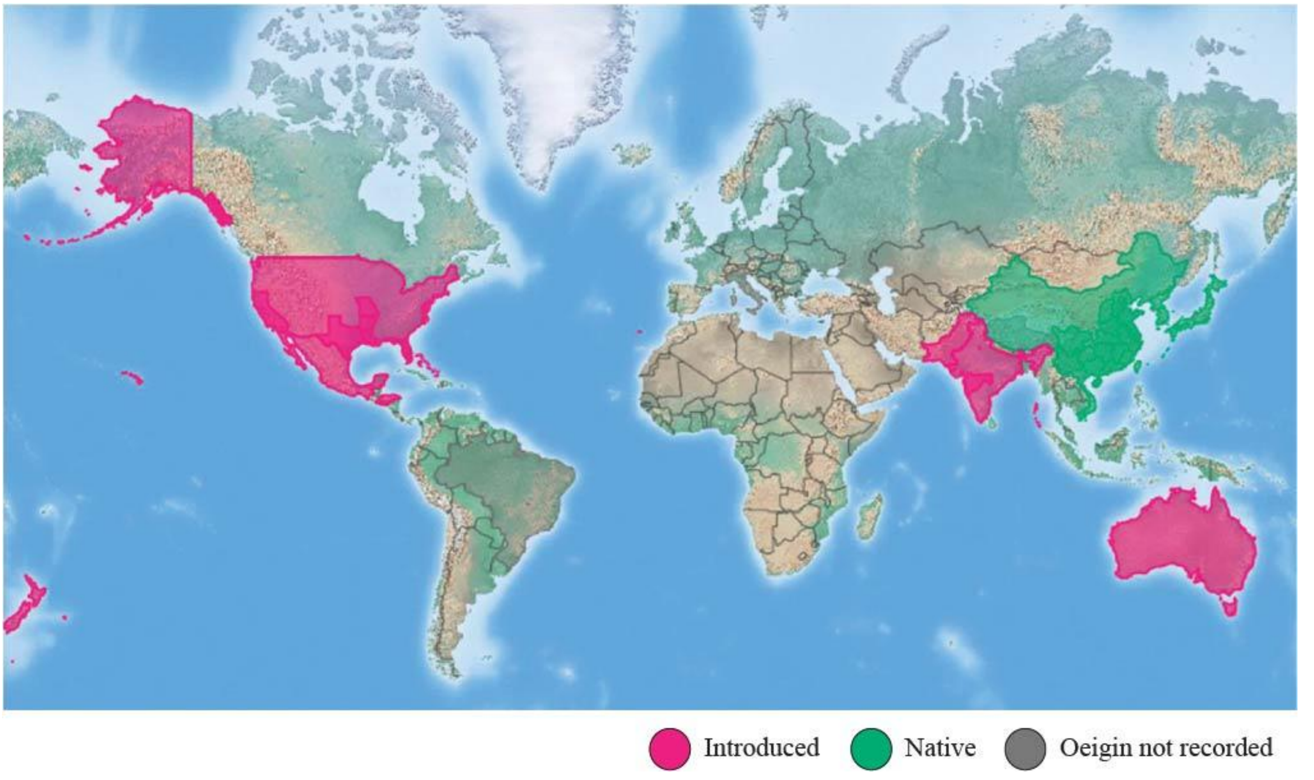


Fig. 1. Distribution of *Trachelospermum jasminoides* (Lindl.) Lem.: Native and Colonized Areas, (Anon., 2025).

Given the above, and the increasing interest in cultivating *THJA* as well as the lack of phenological and morphological studies in Serbia, the present study was undertaken. The main objectives are to determine: 1) the trends of daily, monthly, seasonal, and annual air temperatures during the research period, 2) the maximum and minimum temperatures below 0°C in which *THJA* has existed in Belgrade, and 3) for the first time, their specific impact on the phenology, morphology, and sustainability of *THJA* in the urban landscape on pergolas as elements of green infrastructure under the conditions of a moderate continental climate. Additionally, the purpose of the study is to optimize growing conditions in open green spaces in the Northern Hemisphere by predicting the acclimatization speed and biometric properties of *Trachelospermum jasminoides* (Lindl.) Lem.

## Material and Methods

In the Belgrade municipality of Čukarica, Serbia, a climber *Trachelospermum jasminoides* (Lindl.) Lem. (*THJA*), native to the subtropical biome of western, central, and southern Japan to Vietnam (Middleton, 2014), was identified. This species has naturalized in Pakistan, India, the USA, Mexico, Central America, and the Bahamas (Flora of Pakistan, 2017; Flora of North America Editorial Committee, 2023), as well as in other regions of the Northern and Southern Hemispheres (Fig. 1). The subject of intensive in situ phenomonitoring in this study is a 10-year-old *THJA* plant growing on a pergola, georeferenced at coordinates 41°45'38.26"N and 20°25'12.74"E, at an altitude of 175m, with a western orientation (aspect W) and a slope of 4.3° (slightly inclined terrain). The observations were compared from the Northern Hemisphere network, sourced from the Pl@ntNet database at GBIF (Fig. 2a), where one active phenostation in Belgrade was recorded from 2020 to 2024. Field research confirmed that *THJA* was located in the urban heat island zone, within a street space in the Belgrade municipality of Zvezdara, functioning as a screen (Fig. 2b). It was georeferenced at coordinates 44°48'14.56"N and 20°29'3.49"E, at an altitude of 128m, with a northeastern orientation (aspect NE) and a slope of 5.9° (slightly inclined terrain).

In order to determine the impact of air temperature on this evergreen ornamental flowering climber, the phenophases of leaf development and flowering were monitored over three consecutive years (2022-2024). Using the BBCH scale (Meier, 1997), visual phenological observations were conducted every other day, with the following stages recorded: Principal growth stage 3: Shoot development 1- 39 *BBCH* (Shoots about 90% of final length, leafs fully expanded), Principal growth stage 6: Flowering: beginning of flowering – 61 *BBCH* (beginning of flowering: about 10% of flowers open), full flowering – 65 *BBCH* (otvoreno at least 50% of flowers, first petal folling) i end of flowering - 69 *BBCH* (end of flowering, all petals fallen).

The recorded days of the year were coded using software (Koch *et al*., 2007) in DOY format (1st January – DOY 1, etc.). The Growing Degree Days (GDD) were determined based on daily maximum (Tmax) and minimum (Tmin) air temperatures and the temperature threshold (Tt) using the method of Lalić *et al.* (2021). The temperature threshold of Tt = 5°C was applied, in accordance with the recommendation of the Anon., (2021) for the moderate continental climate conditions, classified as C(f)wa according to Köppen's climate classification in Belgrade. Cfa represents a temperate warm climate with hot summers: (a) moderately warm, rainy climate, (f) hot summers without a distinct dry period, and (w) the least precipitation during the winter half of the year (RHMZ). After forming the sequence of active temperatures for each day, they were summed from 1st January to DOY for the phenological stages of 61 BBCH, 65 BBCH, and 69 BBCH, specifically for each year of the study.

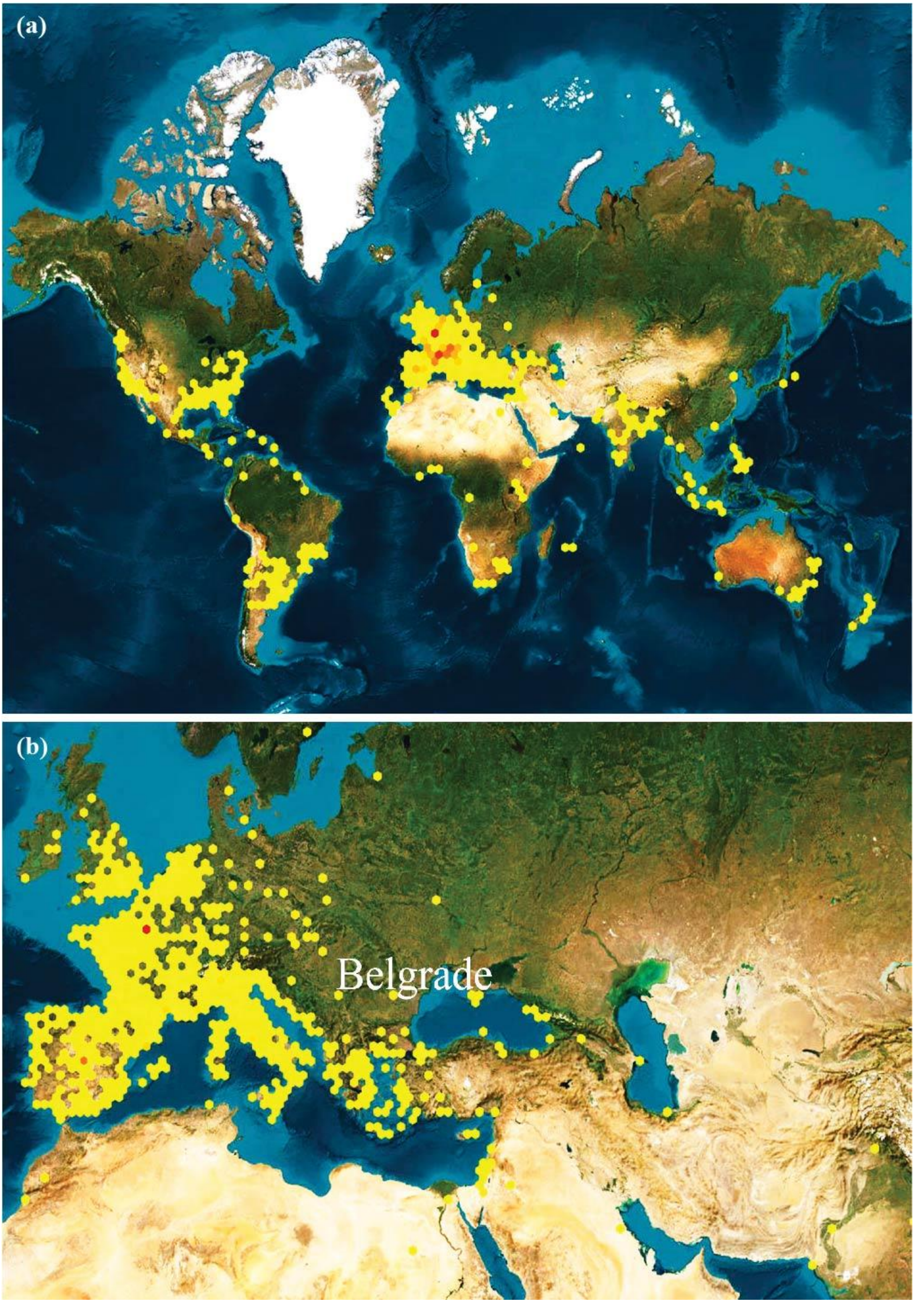


Fig. 2. Stations for observing phenological status of *Trachelospermum jasminoides* (Lindl.) Lem. (a) and the Position of Belgrade in the Pl@ntNet Data Network at GBIF (b).

During field research, photographic material was collected, and interviews were conducted with the garden owner and directors of 10 garden centers and 20 woody plant sales centers in Serbia. Flowers and leaves were also collected for morphometric analysis. Each year, during the full flowering phase (69 BBCH), 100 flowers were collected, and during the full maturity phase (39 BBCH), 100 leaves from the southern part of the canopy were collected and herbarium-preserved. Using the UTHSCSA Image Tool program, the following analyses were performed: leaf length and width, the length of the elongated corolla, and the diameter of the plate-like expanded corolla. For the fresh material, the number of flowers per inflorescence, the number of petals in the corolla, the number of stamens, and the number of pistils were determined.

Climatic data were obtained from the Republic Hydrometeorological Institute of Serbia (RHMZ) (https://www.hidmet.gov.rs/ciril/meteorologija/klimatologija_godisnjaci.php and https://www.ogimet.com/synopsc.phtml.en, accessed on 15 January 2025) from the Košutnjak meteorological station (MS) (44º46'15''N; 20º25'28''E; altitude 203m), located 1,222.42m from the study area. Data were also obtained from the Belgrade Main Meteorological Station (MMS) (44º47'54.44''N; 20º27'53.35''E; altitude 132m), 1,640.5m away from the phenological station of the Pl@ntNet data network at GBIF. Climatic standard normals for air temperature for the reference period 1991-2020 were determined to apply statistical climatological methods of percentiles and associated terciles for the study period.

The study used descriptive statistics, analysis of variance (ANOVA), the non-parametric Mann-Kendall trend test, and the Spearman Rank correlation test. The strength of the correlation was interpreted using the scale by Horvat & Mijoč (2012): 0 (no correlation), 0-0.24 (very weak), 0.25-0.49 (weak), 0.50-0.74 (moderate), 0.75-0.99 (strong to very strong), and 1 (perfect). Only significant correlations with a probability of $p<0.05$ were analyzed. The data were processed using the software packages XLSTAT 2020, Past 4.11, and ArcGIS 10.8/ArcMap 10.8.

## Results and Discussion

**General phenological patterns: leaves and flowers:** The formation of new leaves did not exhibit significant variations over the three consecutive years of the study, correlated with the timing of their formation at the beginning of the climatological summer. Specifically, in our three-year study, as well as in research conducted on the Northern Hemisphere (Fig. 3) during the period 2020-2024 (Pl@ntNet data at GBIF), leaves were in the 39 BBCH phase by mid-June. The phenological patterns of leafing can be characterized by temporal consistency in the years when the observations were made. The patterns in our study do not differ from the results of the Pl@ntNet data at GBIF from the Northern Hemisphere in the same years, based on 729 observations. However, we recorded two periods for the flowering phase 65 BBCH (Fig. 1), the first in June-July 2022 and 2023, and the second in May-June 2024, which was closely aligned with the April-June period for *THJA* in the Northern Hemisphere for 2020-2024 (Pl@ntNet data at GBIF, accessed 27 December 2024), based on 7,513 observations (Fig. 3).

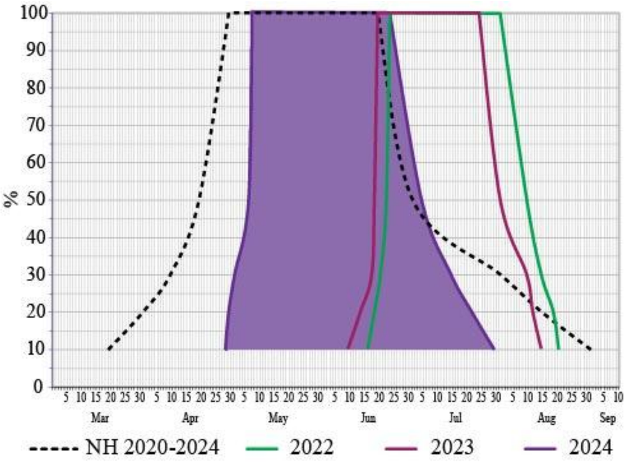


Fig. 3. Phenological patterns of flowering of Star Jasmine in Belgrade (in situ observations during the years of the study) and the Northern Hemisphere for 2020-2024 (NH 2020-2024, Pl@ntNet data at GBIF), based on the percentage of open flowers.

It is evident that in Belgrade, the 65 BBCH phase occurred later by 55, 15, and 7 days (2022, 2023, and 2024) compared to the same phase in the Northern Hemisphere (Pl@ntNet data at GBIF) in those years. However, in 2024, it began earlier by 57 days compared to 2022 and 53 days compared to 2023. The duration of full flowering during the summer (2022 and 2023) was 37 and 30 days, while at the end of spring and the beginning of summer (2024), it lasted 57 days. The length of the full flowering phase is close to the findings of Pl@ntNet data at GBIF for the Northern Hemisphere (2020-2024), based on season (April-July) and flowering duration (51 days), as well as the flowering period in Pakistan (Flora of Pakistan, 2017), which was correlated with the RHMZ statement that 2024 was the hottest year since measurements began in Serbia.

These results are significant for supplementing the list of suitable plants for ornamental and nature-friendly landscape design, which is attractive to birds, bees, butterflies, and other organisms that are displaced due to rapid urban development. They are also important for ecosystem services, as they help control harmful insect populations or assist in pollination (Petrov *et al*., 2024). It is known that day length triggers the phenological phases of many plants in temperate zones (Heide, 1994), but also large-scale processes such as El Niño, which was active during the study years (Anon., 2024). The potential relationship between flowering and radiation, which is significantly correlated with the differences in maximum and minimum air temperatures, suggests that warm, sunny days are more suitable for flower opening (Ocokoljić *et al.*, 2023, Čukanović *et al*., 2024).

Considering this and that plant growth and development are proportional to accumulated heat sums (GDD), which measure the accumulation of heat above the temperature threshold over 24 hours rather than the daily air temperatures during phenological phases (Réaumur, 1735), GDD were determined for the elements of the flowering phenological pattern of *Trachelospermum jasminoides* in the period 2022-2024 (Table 1).

**Table 1. Elements of the phenological flowering patterns of star jasmine in Belgrade.**

| Observation Year | 61 BBCH DOY* | 61 BBCH GDD** | 65 BBCH DOY* | 65 BBCH GDD** | 69 BBCH DOY* | 69 BBCH GDD** |
|---|---|---|---|---|---|---|
| 2022 | 168 | 1198.2 | 174 | 1309.1 | 233 | 2506.6 |
| 2023 | 161 | 1014.9 | 171 | 1164.2 | 227 | 2238.8 |
| 2024 | 120 | 781.3 | 129 | 898.9 | 212 | 2455.7 |
| **GDD for DOY values from 2024 in the previous two years of the study** | | | | | | |
| 2022 | 120 | 438.9 | 129 | 552.4 | 212 | 2081.1 |
| 2022 | 120 | 490.1 | 129 | 590.1 | 212 | 1977.8 |

*DOY – Days of the year

**GDD Accumulated heat sums (°C), based on data from the Košutnjak meteorological station

**Table 2. Average seasonal air temperatures, corresponding percentiles and terciles, and their deviations for 2024 compared to the 1991-2020 normal according to MS Košutnjak and GMS Belgrade.**

| Tmean 2024 (°C) | Perc. Cat.* | Tmean (°C) 1991-2020 | Deviation (°C) | 1991-2020 33.-Perc. | 1991-2020 50.-Perc. | 1991-2020 66.-Perc. | Terc. Cat. ** |
|---|---|---|---|---|---|---|---|
| **MS Košutnjak** | | | | | | | |
| **Winter** | | | | | | | |
| 7.1 | EW | 2.5 | 4.6 | 1.4 | 2.2 | 3.4 | 1 |
| **Spring** | | | | | | | |
| 15.2 | EW | 12.8 | 2.4 | 12.4 | 13.0 | 13.4 | 1 |
| **Summer** | | | | | | | |
| 26.2 | EW | 22.6 | 3.6 | 22.1 | 22.7 | 22.8 | 1 |
| **GMS Belgrade** | | | | | | | |
| **Winter** | | | | | | | |
| 7.4 | EW | 2.9 | 4.5 | 1.7 | 2.6 | 3.7 | 1 |
| **Spring** | | | | | | | |
| 15.8 | EW | 13.4 | 2.4 | 13.2 | 13.6 | 13.9 | 1 |
| **Summer** | | | | | | | |
| 27.1 | EW | 23.2 | 3.9 | 22.5 | 23.2 | 22.8 | 1 |

* Extremely warm (EW), Very warm (VW), Warm (W), Normal (N), Very cold (VC), Extremely cold (EC),

** Warm (1), Normal (0), Cold (-1), categorization of the RHMZ

The lowest heat sum for the 61 BBCH phase (781.3°C) occurred on DOY 120 in 2024, while the highest (1198.2°C) occurred on DOY 168 in 2022. However, the GDD for DOY 120 in 2022 and 2023 was lower by 759.3°C and 524.8°C, respectively, compared to 2024 (Table 1). For the 65 BBCH phase, the minimum heat sum (898.9°C) was reached on DOY 129 in 2024, while the maximum (1309.1°C) was recorded on DOY 174 in 2022. Comparing the GDD sums for DOY 129, it was observed that 2022 had 756.7°C, while 2023 was lower by 574.1°C compared to 2024 (Table 1). Flowering ended (69 BBCH) with the lowest sum (2238.8°C) on DOY 227 in 2023 and the highest sum (2506.6°C) on DOY 233 in 2022. However, the GDD for DOY 212 in both 2022 and 2023 was in close range with the GDD for 69 BBCH in 2024, which was confirmed by the Mann-Kendall trend test, indicating the insignificance of GDD at the end of flowering and the significance of decreasing DOY values (S -5, p 0.0042) across all phenological stages of flowering.

The values of Spearman's Rank correlation coefficient (ρ) for the phenophases: 61 BBCH DOY and 61 BBCH GDD, 65 BBCH DOY, 65 BBCH GDD, and 69 BBCH DOY; 61 BBCH GDD and 65 BBCH DOY, 65 BBCH GDD and 69 BBCH DOY; 65 BBCH DOY and 65 BBCH GDD and 69 BBCH DOY; and 69 BBCH DOY and 69 BBCH DOY of flowering were statistically significant. A complete (ρ=1) constantly increasing correlation was confirmed, indicating that the phenological patterns are influenced by the rise in air temperature, and that the days of the year are not as significant as the accumulated heat sums. The determined values align with the extremely warm winter, spring, and summer of 2024 based on the percentile's method, and warm based on the terciles method, according to the data from the Košutnjak meteorological station and the Beograd Main Meteorological Station (Table 2).

The summer of 2024 had five very intense heatwaves with a thermal stress index (THI – subjective temperature feeling) 23 days above 40°C and 83 days above 30°C (RHMZ), which influenced flowering. The impact of air temperature on the GDD values for all elements of the flowering phenological pattern during the study was evident, therefore, the average daily air temperatures for the DOY elements of the flowering phenological pattern in 2024 across the three years of the study are shown (Fig. 4).

**Statistical analysis**

The average daily air temperatures and phenological observations showed that the average value of the mean daily air temperatures from January 1 to 61 BBCH (120 DOY) was: 10.3°C (2024), 7.5°C (2023), 6.7°C (2022) and 6.4°C (reference period 1991-2020); from January 1 to 65 BBCH (129 DOY): 10.8°C (2022), 8.1°C (2023), 7.4°C (2024) and 7.0°C (reference period 1991-2020), and from January 1 to 69 BBCH (212 DOY): 15.8°C (2024), 13.3°C (2023), 13.8°C (2022) and 12.6°C (reference period 1991-2020). An increase in the mean daily temperatures was observed for 0.3-3.7°C until 120 DOY, 0.4-3.8°C until 129 DOY, and 0.7-3.2°C until 212 DOY compared to the 1991-2020 normal for the same period. The results are consistent with the Anon., (2019) report that many regions above land are experiencing more warming than the global annual average, especially during different seasons. Table 2 shows seasonal air temperatures and deviations for 2024 compared to the reference period normal from MS Košutnjak and GMS Belgrade.

The obtained results correlated with percentiles and terciles for winter, spring, and summer, which were classified as extremely warm and warm, respectively, influencing a significant shift in the flowering phenophase (Table 2). The findings of our research, as well as those of Anon., (2009) and Ocokoljić *et al*. (2024), confirm that an earlier start and longer flowering phenophase are conditioned by higher air temperatures. As Rojas-Sandoval (2022) indicates, optimal mean annual air temperatures for *THJA* range between 12°C (min) and 26°C (max), and the mean annual air temperatures for the MS Košutnjak in 2020/2021/2022/2023/2024 were 13.6°C / 13.4°C / 14.1°C / 14.4°C / 15.3°C, compared to 12.8°C for the reference period, and for the MMS Belgrade 13.9°C / 13.8°C / 14.5°C / 14.9°C / 15.9°C, with the reference period being 13.2°C. Through an integrative approach to phenological patterns of leafing and flowering and air temperatures, the adaptability of the species has been confirmed in the context of climate change over the past decade (2015-2024), during which *THJA* has existed in the studied private garden, as well as for five years along the traffic route (2020-2024) in the urban landscape of Belgrade. The sustainability of these elements is supported by their location: the pergola is oriented westward between private buildings with a P+1 storey structure, and the screen is to the northeast in a street where collective residential buildings with a P+5 storey structure are located. Both elements are protected from the impact of the southeast and northwest winds, which are the dominant and cold winds in Belgrade, to which *THJA* is sensitive (Anon., 2025; Pl@ntNet data at GBIF, 2024; POWO, 2025; Anon., 2025).

As Clifford & Kobayashi (2010) state that *THJA* is tolerant to mild frosts, temperatures below 0°C were analysed from 2016 to 2024 (Fig. 5a-i), since, according to the garden owner's statement, *THJA* has been part of vertical greening in Belgrade from that time. The planting period aligns with interviews with garden centre managers, who confirmed that *THJA*, as a potted plant for interiors, was commercialised on the Serbian horticultural market 12 years ago, imported from the Netherlands and Italy.

The lowest temperature recorded was on January 8, 2017, at -15.5°C (Fig. 5b), falling into the category of severe frosts, as a day with severe frost is, by definition, a day with a minimum daily air temperature below -10°C (RHMZ). On the same year, on January 7, the maximum temperature was -10.0°C, and there were 6 consecutive frost days (frost days are those with a maximum daily temperature below 0°C, RHMZ) from January 6 to 11, followed by 9 frost days (January 18-26) and 2 (January 28 and 29). The winter of 2017 had a total of 30 frost days. January 2017 (Fig. 5b) had 18 frost days, and February of the same year had 12 frost days (frost days are those with a minimum daily temperature below 0°C, RHMZ). Since *THJA* was planted in the spring of 2015, it was evident that young plants could tolerate severe frosts (Fig. 5a and b), as well as multiple consecutive frost days. The following years had fewer frost and freezing days (Fig. 5c-h), with 2024 standing out (Fig. 5i) with only 3 frost days (-7.5°C to -2.2°C) and 21 freezing days (-6.5°C to -0.1°C). Based on our research, it can be concluded that *THJA* is tolerant to frosts down to -15.5°C in the conditions of a temperate continental climate at altitudes up to 200 meters above sea level.

The results of our study confirm that seasonal changes, i.e. landscape phenology, are an essential component of the identity and perception of the landscape, which simultaneously generate orientation in space and time. This is why *THJA* deserves greater attention in research, planning, and design.

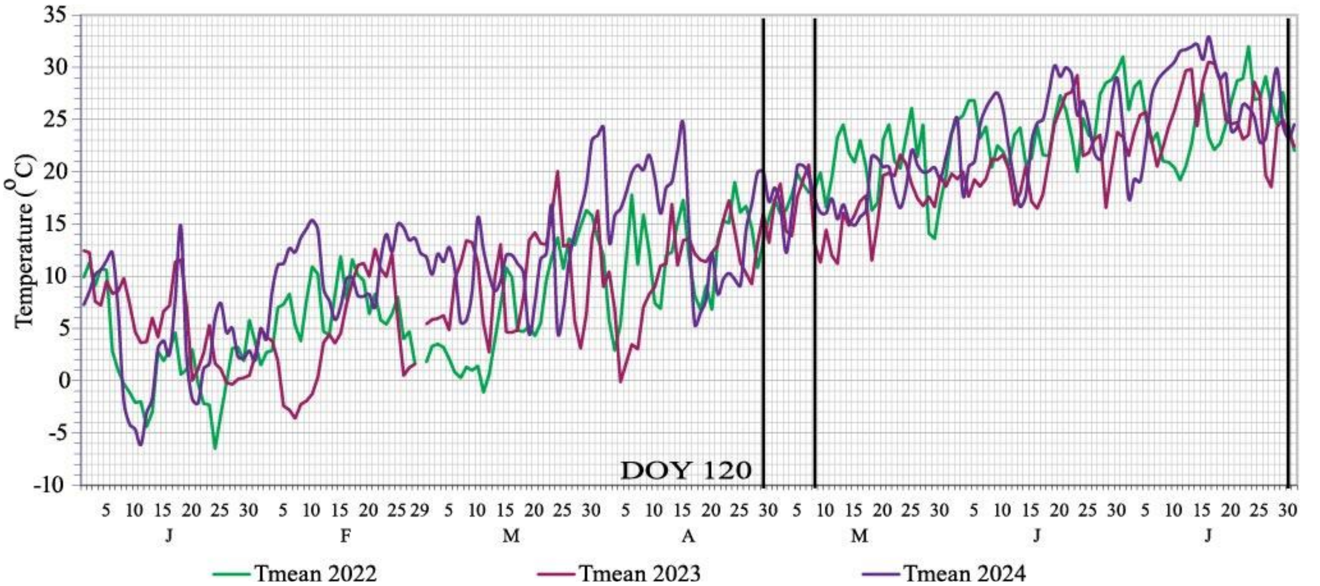


Fig. 4. Graphical representation of average daily temperatures for the study years with DOY phase markings of 61 BBCH, 65 BBCH, and 69 BBCH for 2024 Star Jasmine, based on data from the Košutnjak meteorological station.

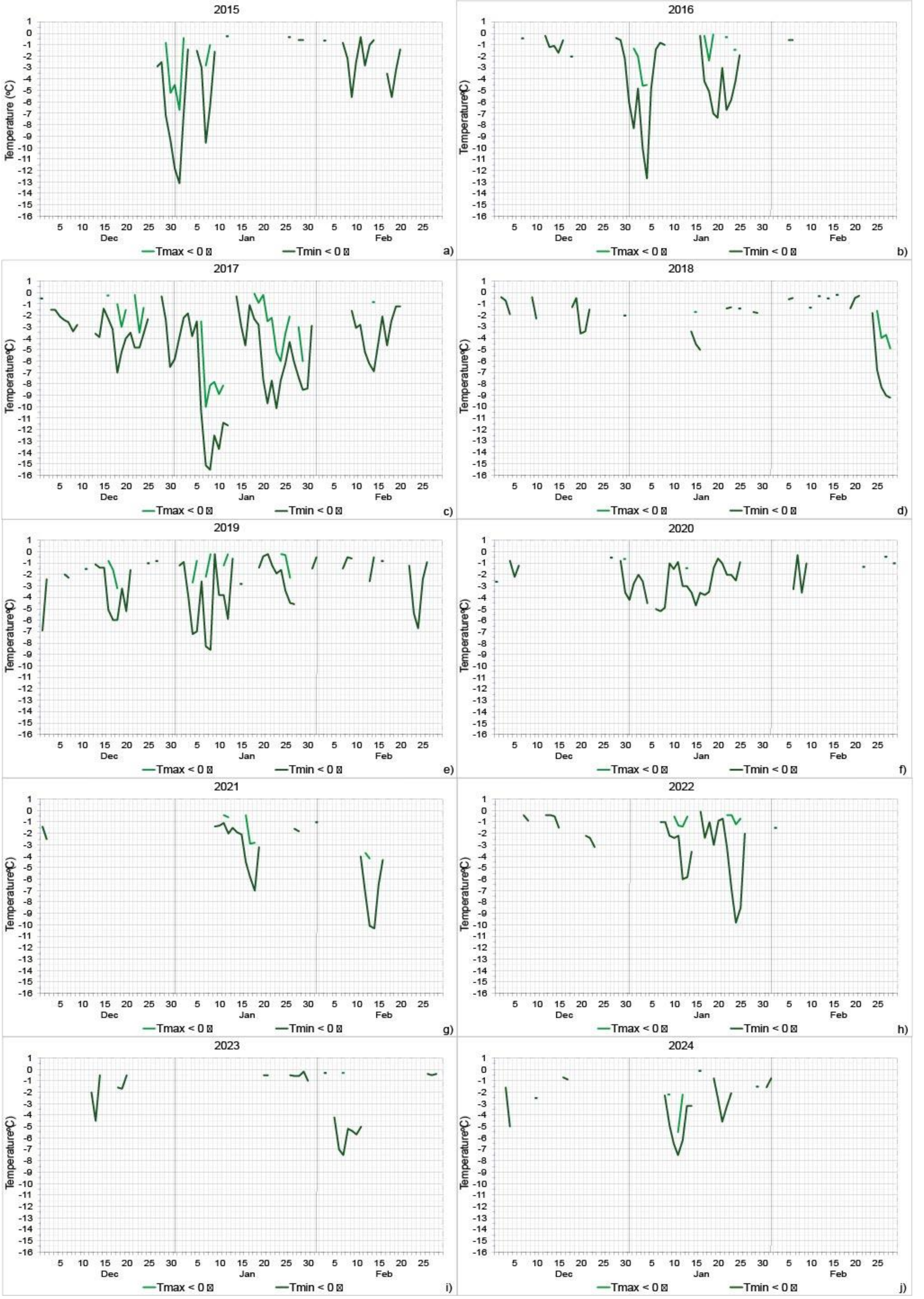


Fig. 5. Daily cycle of maximum and minimum air temperatures below 0°C for climatological winters in the period 2016-2024, for MS Košutnjak.

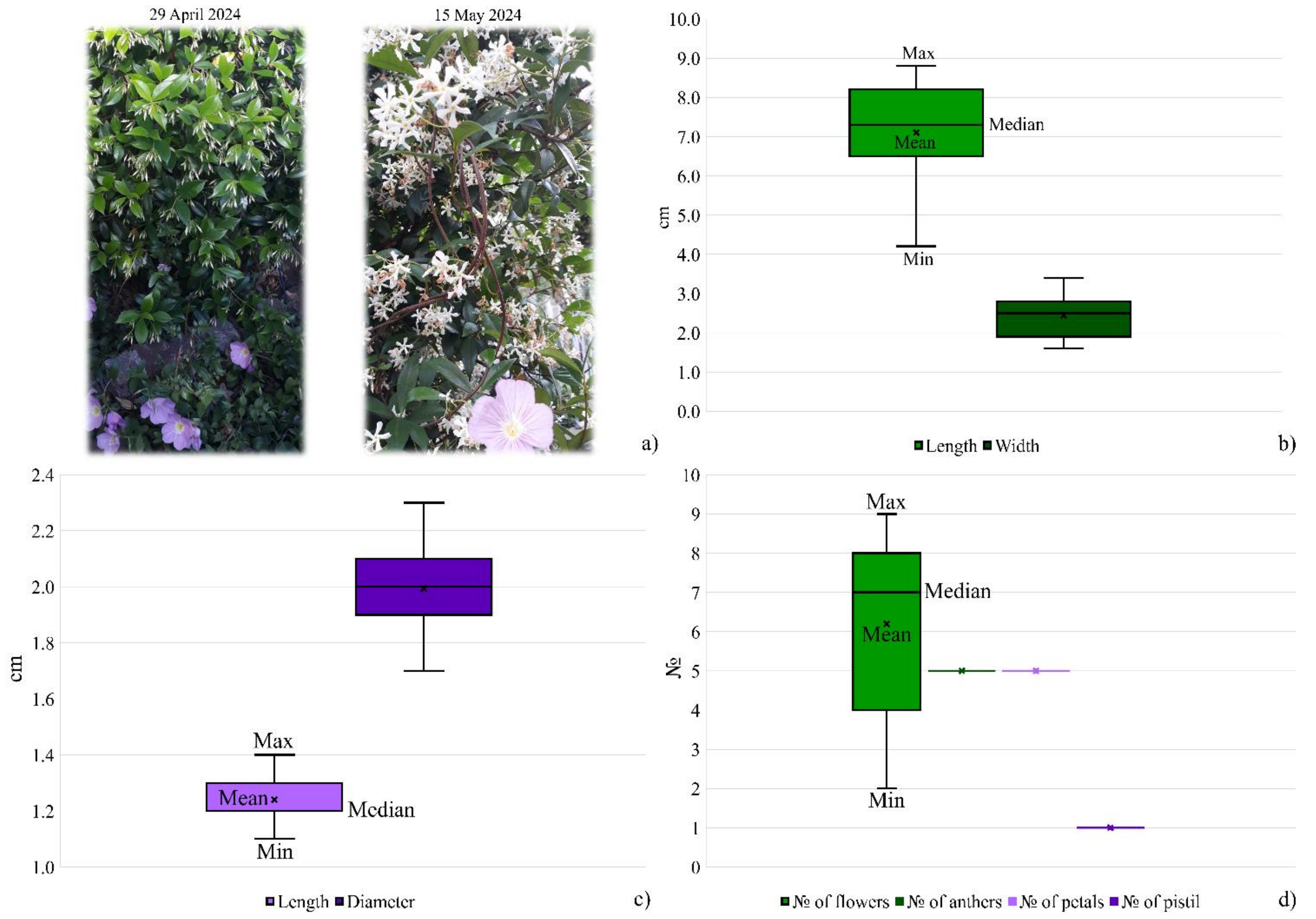


Fig. 6. Visual aspects of the pergola details with Star Jasmine and ground cover of *Oenothera speciosa* Nutt. (a) and biometric characteristics of leaves (b), inflorescences, and flowers (c and d).

**Morphometric studies of the leaf and floral structures:** Considering that *THJA* is an evergreen species with a long flowering phenophase during the summer, and that there is a small number of woody climbers with such characteristics in Belgrade. The metric and morphological characteristics of leaves, inflorescences, and flowers were examined (Fig. 6). The leaf length ranged from 4.20 cm to 8.80 cm (Fig. 6b). The obtained result aligns with the Flora of North America Editorial Committee (2023) and NRCS (2023) database, which reports a leaf length range of 2.00 cm to 10.00 cm. The standard deviation was moderate (1.38), as was the coefficient of variation (19.47), indicating a medium level of variability. The leaf width ranged from 1.60 cm to 3.40 cm (Fig. 6b), which is within the 1.00 cm to 4.50 cm range specified by the Flora of North America Editorial Committee (2023) and NRCS (2023). The standard deviation was low (0.57), but the coefficient of variation was high (23.17), suggesting greater variability. The insignificance between repetitions (years of study) was confirmed by the ANOVA test, with $p<0.0001$, for both leaf length (F = 0.31) and leaf width (F = 0.52). The Spearman Rank correlation coefficient, with a probability of $p<0.05$, between leaf length and width confirms a moderate positive correlation (0.59034), indicating that as leaf length increases, so does its width.

The leaves are opposite, oval to lanceolate, with a smooth margin and a pointed tip. Throughout the year, over a 10-year period, they were dark green, as stated by the garden owner, which is also noted by Gilman (1999) for the species cultivated in Florida. However, in areas where *THJA* is native, the leaves turn a bronze-red colour in winter (Middleton, 2014). Additionally, it should be noted that, according to Wunderlin & Hansen (2011), changes in leaf colour are not always seasonal and may be influenced by an unfavorable substrate condition.

The number of flowers in the inflorescence and the dimensions of the corolla are important traits for ornamental flowering plants. The results of the study highlight the length of the tubular corolla, which ranged from 1.10 to 1.40 cm, as well as the diameter of the dish-like expanded part of the corolla, which ranged from 1.70 to 2.30 cm (Fig. 6c). Our results exceeded the values for tubular corolla length (0.5 to 1.0 cm) and the diameter of the dish-like expanded corolla (1.0 to 2.0 cm) reported by the Flora of North America Editorial Committee (2023) and NRCS (2023). Low variability is confirmed by the low values of standard deviation (0.11 and 0.18) and coefficients of variation (8.51 and 8.79). Statistical insignificance between the years of the study (repetitions) was confirmed by the ANOVA test, with $p<0.0001$, and F values of 5.3 and 4.5. The Spearman Rank correlation coefficient, with a probability of $p<0.05$, between the length of the corolla and the diameter of the dish-like expanded corolla was not statistically significant.

The number of flowers in the inflorescences ranged from 2 to 9 (Fig. 6d). The standard deviation was low (2.27), but the coefficient of variation was high (36.68), indicating greater variability. The ANOVA F value between years was not statistically significant (2.5). The number of petals in the dish-like expanded corolla was 5, and there were 5 stamens, while all flowers had only one pistil (Fig. 6b). Our observations align with the findings of Gilman (1999) and Middleton (2014), who state that the corolla ends with 5 obliquely positioned, curved lobes that resemble a spiral turning counterclockwise, as well as that the corolla contains 5 stamens. The Flora of North America Editorial Committee (2023) and NRCS (2023) report that the number of petal lobes in the corolla can be 4 or 5. To our knowledge, except for the note that the flowers are bisexual (Gilman, 1999; Rojas-Sandoval, 2022), there is no data on the number of flowers in the inflorescences or the number of pistils in the flowers. We did not observe fruiting, which is expected as cultivated *THJA* individuals in the Northern Hemisphere do not produce fruit and seeds (Gilman, 1999; Clifford & Kobayashi, 2010).

## Conclusions

The findings of intensive *in situ*, pioneering research in Serbia over three consecutive years stand out due to important information on the morphological elements of leaves, inflorescences, flowers, and contributions to knowledge on the acclimatization and sustainability of the species. Based on these findings, the identification key for *THJA* can be revised, and databases such as Pl@ntNet data, CABI, GBIF, Kew, and EPPO can be updated. We suggest that a new phenological station, the subject of this study, be included in the Pl@ntNet data phenological network, especially since the observed subject could also be *Oenothera speciosa* Nutt., functioning as a ground cover for ten years beside the pergola with Star Jasmine, while the GBIF database in Serbia does not have a phenostation for this species. Phenomonitoring should be continued to gain insight into the causes and consequences of shifts in phenological patterns and to address questions related to the spatial and temporal organization of ecological communities and interactions.

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## References

Anonymous. 2009. Guidelines for Plant Phenological Observations, WMO/TD No. 1484. https://library.wmo.int/ doc_num.php?explnum_id=9414 (accessed on 28 December 2024).

Anonymous. 2019. Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. (Eds.): Shukla, P.R., J. Skea, E. Calvo Buendia, V. Masson- elmotte, H.-O. Pörtner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P.Vyas, E. Huntley, K. Kissick, M. Belkacemi and J. Malley. Cambridge University Press, Cambridge, UK and New York, NY, USA.

Anonymous. 2021. State of the Global Climate 2021: WMO Provisional Report. World Meteorological Organization (WMO), 47. https://library.wmo.int/ doc_num.php? explnum_id=10859 (Access Date: 30 September 2024)

Anonymous. 2024. El Nino/ La Nina, Available from: https://wmo.int/sites/default/files/2024-09/ WMO ENLN_ Update-September-2024-fin.pdf (Access Date: 10 January 2025)

Anonymous. 2025. CABI Compendium. Wallingford, UK: CAB International. Available: https://www.cabidigitallibrary.org/ journal/cabicompendium (Access Date: 6 January 2025)

Anonymous. 2025. https://pfaf.org/user/cmspage. aspx?pageid=174 (Access Date: 5 January 2025)

Anonymous. 2025. The European and Mediterranean Plant Protection Organization. Available: https://gd.eppo.int/ taxon/TCHJA (Access Date: 10 January 2025)

Clifford, P. and K. Kobayashi. 2010. *Non-invasive landscape plants with fragrant flowers. Cooperative Extension Service*. College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa. Ornamentals and Flowers, OF-46, 9 p.

Crimmins, T.M., M.A. Crimmins and C.D. Bertelsen. 2010. Complex responses to climate drivers in onset of spring flowering across a semi-arid elevation gradient. *J. Ecol*., 98: 1042-1051.

Čukanović, J., M. Ljubojević, S. Djordjević, T. Narandžić, Dj. Petrov and M. Ocokoljić. 2024. The Impact of Climate Variability on the Blooming of *Fraxinus ornus* 'Globosa' as a Component of Novi Sad's (Serbia) Green Infrastructure. *Sustainability*, 16: 8404. https://doi.org/10.3390/su16198404

Flora of China Editorial Committee. 2017. Flora of China. St. Louis, Missouri and Cambridge, Massachusetts, USA: Missouri Botanical Garden and Harvard University Herbaria. http://www.efloras.org/flora_page.aspx?flora_id=2 (Access Date: 29 December 2024)

Flora of North America Editorial Committee. 2023. Flora of North America North of Mexico 14: 1-505. Oxford University Press, New York, Oxford.

Flora of Pakistan. 2017. Flora of Pakistan/Pakistan Plant Database (PPD). St. Louis, Missouri and Cambridge, Massachusetts, USA: Tropicos website. Available: http://www.tropicos.org/Project/Pakistan (Access Date: 6 January 2025).

Forrest, J.R.K. 2015. Plant–pollinator interactions and phenological change: what can we learn about climate impacts from experiments and observations? *Oikos*, 124: 4-13.

Gilman, E.F. 1999. *Trachelospermum jasminoides*. Fact sheet FPS-586. Environmental Horticulture Department. Extension Service. University of Florida. https://hort.ifas. ufl.edu/shrubs/TRAJASA.PDF (Access Date: 29 December 2024).

Hansen, G. 2010. Arbor, Trellis, or Pergola – What's in your garden? A Mini-Dictionary of Garden Structures and Plant Forms: ENH1171 EP432, 8. *EDIS*, 2010(6). Gainesville, FL. https://doi.org/10.32473/edis-ep432-2010.

Heide, O.M. 1994. Control of flowering and reproduction in temperate grasses. *New Phytol*., 128: 347-362.

Horvat, J. and J. Mijoč. 2012. *Osnove statistike* [Basics of statistics], Naklada Ljevak d.o.o., Zagreb, Croatia.

Koch, E., E. Bruns, F.M. Chmielewski, C. Defila, W. Lipa and A. Menzel. 2007. Guidelines for plant phenological observations. https://www.researchgate.net/publication/266211199

Lalić, B., J. Ejcinger, A. Dalamarta, S. Orlandini, A. Firanj Sremac and B. Paher. 2021. *Meteorologija i klimatologija za agronome* [Meteorology and climatology for agronomists]. Univerzitet u Novom Sadu-Poljoprivredni fakultet. Novi Sad, Serbia.

Meier, U. 1997. *BBCH-Monograph, Growth stages of plants*. Entwicklungsstadien von Pflanzen. Estadios de las plantas. Stades dedéveloppement des plantes. Blackwell Wissenschafts- erlag Berlin, Wien, Austria.

Middleton, D.J. 2014. *Flore du Cambodge du Laos et du Viêt-Nam.* 33: 1-276. Muséum National d'Histoire Naturelle, Paris.

NRCS. 2023. *Trachelospermum jasminoides*. PLANTS Database. United States Department of Agriculture (USDA). https://plants.usda.gov/plant-profile/TRJA (Access Date: 29 December 2024).

Ocokoljić, M., Dj. Petrov, N. Galečić, D. Skočajić, O. Košanin and I. Simović. 2023. Phenological Flowering Patterns of Woody Plants in the Function of Landscape Design: Case Study Belgrade. *Land*, 12: 706. https://doi.org/10.3390/land12030706.

Ocokoljić, M., Dj. Petrov, O. Košanin, N. Galečić, D. Skočajić, D. Vujičić and I. Simović. 2024. Phenological patterns of *Fraxinus ornus* L. flowering in the context of ecosystem services preservation in urban forests: a case study of Košutnjak, Belgrade, Serbia. *Sylwan*, 168(11): 801-821. https://doi.org/10.26202/sylwan.2024047

Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. *Ann. Rev. Ecol. Evol. Syst*., 37: 637-669.

Petrov, Dj., M. Ocokoljić, N. Galečić, D. Skočajić and I. Simović. 2024. Adaptability of Prunus cerasifera Ehrh. to Climate Changes in Multifunctional Landscape. *Atmosphere*, 15: 335. https://doi.org/10.3390/atmos15030335

Pl@ntNet data at GBIF. 2024. https://identify.plantnet.org/k-world-flora/species/Trachelospermum%20jasminoides%20(Lindl.)%20Lem./data (Access Date: 27 December 2024)

POWO. 2025. Plants of the World Online. Facilitated by the Royal Botanic Gardens, Kew. https://powo.science.kew.org/ (Access Date: 10 January 2025)

Réaumur, R.A.F. 1735. Observations du thermomètre faites à Paris pendant l' année 1735 comparée sa veccelles quiontété faitessous la ligne à l' Ile de France, à Algere tenquelques-unes de nos îles de l' Amérique, Académie Royale des Sciences, 545-580.

Rebetez, M. and M. Reinhard. 2008. Monthly air temperature trends in Switzerland 1901–2000 and 1975–2004. *Theor Appl Climatol*, 91: 27–34. doi:10.1007/s00704-007-0296-2

Richardson, A.D., T.A. Black, P. Ciais, N. Delbart, M.A. Friedl, N. Gobron, D.Y. Hollinger, W.L. Kutsch, B. Longdoz, S. Luyssaert. 2010. Influence of spring and autumn phenological transitions on forest ecosystem productivity. *Philosophical Transactions of the Royal Society*, B 365: 3227-3246.

Rojas-Sandoval, J. 2022. Trachelospermum jasminoides (star-jasmine), Cabi compendium 52837, CABI Compendium. https://www.cabidigitallibrary.org/doi/10.1079/cabicompendium.52837

Stevens, P.F. 2012. Angiosperm Phylogeny Website. http://www.mobot.org/MOBOT/research/APweb/ (Access Date: 2 January 2025)

TGA Australia. 2017. Profile for Trachelospermum 'Star Jasmine. http://www.tgaaustralia.com.au/list_product_details.php?pid=829 (Access Date: 2 January 2025)

Wellington, N. 2017. Chinese Star Jasmine Trachelospermum jasminoides. https://www.hedge.co.nz/chinese-star-jasmine (Access Date: 2 January 2025

Wunderlin, R.P. and B.F. Hansen. 2011. *Guide to the vascular plants of Florida*, 3rd edition. University Press of Florida, Gainesville, Florida. 783 pp.