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PRUNUS SPINOSA L. IN PERI-URBAN ENVIRONMENTS UNDER CLIMATE CHANGE CONDITIONS: VULNERABILITY AND ADAPTABILITY

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SUMMARY

This study aims to analyze the impact of climatic variables on the fruiting of blackthorn (Prunus spinosa L.), a species which serves as both a food source and a habitat, offering birds shelter and providing other species with refuge from predators. Accordingly, blackthorn fruiting was recorded through field research in the peri-urban green infrastructure of Belgrade over 18 consecutive years. Urban edges are often the sites of expanding artificial surfaces, habitat fragmentation, and complex land-use transitions, including agricultural intensification and abandonment, which collectively increase pressures on residual semi-natural ecosystems. The integration of floristic sampling, phenological observations, landscape measures, and climatic variables allowed for an exploration of landscapes where blackthorn is successfully incorporated into semi-natural ecosystem remnants within a peri-urban context. The results obtained indicate that the phenological patterns of blackthorn, in response to climate change, demonstrate both adaptability and vulnerability to extreme climatic events during the flowering phase. In 2024, flowering began 6 days earlier than the earliest recorded start date and 43 days earlier than the latest start recorded over the previous 17 years. Regarding the fruiting (phonological) pattern, the average fruit maturation period was 288 days, while in 2024 it occurred 61 days earlier. The statistical significance of earlier fruit maturation and reduced accumulated heat requirements for fruit ripening was confirmed, revealing that as temperatures rise, key phenological events occur earlier with reduced heat accumulation, indicating a dependency on climatic parameters. Understanding the mechanism of phenological patterns is crucial for promoting effective environmental management practices and biodiversity conservation. The study also contributes to the potential application of its findings in designing green spaces in other peri-urban regions, supporting the sustainable development of complex peripheral landscapes by integrating blackthorn into green infrastructure planning.

Key words: *landscape architecture, blackthorn, green infrastructure, phenological patterns, climate change*

Abbreviations: RP – fruit ripening; DOY – day of the year; GDD – growing degree days; BF – flowering beginning; FF – full flowering; EF – end of flowering

INTRODUCTION

There is a long-standing tradition of observing phenological events in Europe. When recorded over several decades, such observations serve as a valuable resource for studying global climate change (Schwartz, 2003). Temporal shifts in phenological patterns and key events have been documented for many taxa and communities (Visser & Both, 2005; Ocokoljić et al., 2023). The studies by Chmielewski & Rötzer (2002) and Schleip et al. (2009) have established that spring phenological events are occurring earlier, while autumn events are delayed across Europe.

However, shifts in phenophases vary significantly between regions, with spring phenophases in Western and Central Europe starting up to 4 weeks earlier, whereas in Eastern Europe, they are delayed by 2 weeks (Menzel et al, 2006). These phenological changes show close correlations with increasing average air temperatures (Menzel et al, 2006; Ocokoljić et al., 2023; Petrov et al., 2024). Furthermore, assessments of the lengthening growing season for European species indicate that a 1°C increase in mean temperatures in February, March, and April advances the start of the growing season by approximately 7 days (Chmielewski & Rötzer, 2002).

Research on the phenology of blackthorn is largely limited to studies conducted in Belgium, where a delayed flowering onset in Belgian provenances compared to southern European provenances has been documented, and Romania, where a correlation has been confirmed between bud break timing and rising air temperatures in late winter and early spring (Vander Mijnsbrugge et al., 2016; Cosmulescu & Gavrila Calusaru, 2020). A seventeen-year analysis in Serbia found an earlier onset of blackthorn flowering in ecotones, likely driven by local adaptation (Ocokoljić et al., 2023). Further research on the correlation between climatic parameters and phenological patterns is essential, as *Prunus spinosa* L. is a common species in European deciduous forests, hedgerows, scrublands, and open agricultural areas, playing a vital role in green infrastructure (Körber-Grohne, 1996). Additionally, blackthorn is a significant honey-producing species pollinated by insects and a wild fruit species dispersed by birds. Its presence enhances biodiversity, aids in the restoration of historical landscapes, and supports habitat preservation for birds and other wildlife (Ocokoljić & Petrov, 2022).

This study aims to identify and quantify the fruiting trend and ecological functionality of *Prunus spinosa* L. in relation to climatic fluctuations in the peri-urban zone of Belgrade over a period of 18 consecutive years. For this purpose, the impacts of air temperature, precipitation, and insolation on the phenology of blackthorn and the bioactive components in its fruits were evaluated, with a focus on the hottest recorded year, 2024.

MATERIAL AND METHODS

The research area consisted of a linear population of blackthorn, extending from east-southeast (ESE) to west-northwest (WNW) between the coordinates 44º43'36.30"N, 20º19'36.60"E, and 44º43'36.60"N, 20º19'36.12"E, at an altitude of 112m. This 140.07 m span lies along a local road, adjacent to a sunflower plantation in the southwestern peri-urban zone of Belgrade.

To determine the influence of climatic parameters on blackthorn fruiting from 2007 to 2024, the extended BBCH scale (Meier, 1997) was applied. Phenological observations of fruiting were conducted visually at 2-day intervals, recording the fruit ripening date (RP), i.e. the day when fruits acquired the characteristic color of mature fruits. The dates recorded were converted into the days of the year (DOY), where DOY 1 corresponds to January 1st, which serves as the starting point for accumulating thermal sums for calculating the growing degree days (GDD), applying a 5°C temperature threshold for temperate continental climate conditions, as per Lalić et al. (2021). GDDs were calculated by summing the active temperature accumulations at the population level for each of the 18 years.

During phenological observations in 2024, additional dates were recorded for the beginning of flowering (BF) (more than 10% of flowers open), full flowering (FF) (more than 50% of flowers open), and end of flowering (EF) (fewer than 20% of flowers remaining), accompanied by producing photographic documentation.

Data processing involved descriptive statistics, and relationships between climatic parameters and the fruit ripening phenological event were investigated using the Mann-Kendall trend test and Spearman’s rank correlation coefficient (ρ), utilizing XLSTAT 2020 and Past4.11 software packages. To assess climatic impacts, data from the Republic Hydrometeorological Service of Serbia (RHMS, 2024) were sourced from the Main Meteorological Station in Surčin (φ 44º47'54.44"N; λ 20º27'53.35"E), located in the peri-urban zone of Belgrade with environmental conditions comparable to those of the study population. The term “normal” in this study refers to the climatological standard norm, i.e. the average values of climatic elements for the reference period 1991-2020. Statistical climatological methods, including percentiles and associated terciles (RHMS), were applied, where the n-th percentile represents the value below which n percent of data ranks in ascending order. The bioactive components in blackthorn fruits were analyzed using standard methods for functionality assessment.

RESULTS AND DISCUSSION

The analysis of phenological characteristics confirmed that flowering and fruit ripening times varied depending on environmental conditions (Glowacka et al., 2021), while phenophases were influenced by climatic variables in previous studies (Ocokoljić et al., 2023). Accordingly, the mean seasonal air temperatures and precipitation levels from 2007 to 2024 (for autumn from 2007 to 2023) are presented in Figures 1a–d, compared to the reference period of 1991−2020.

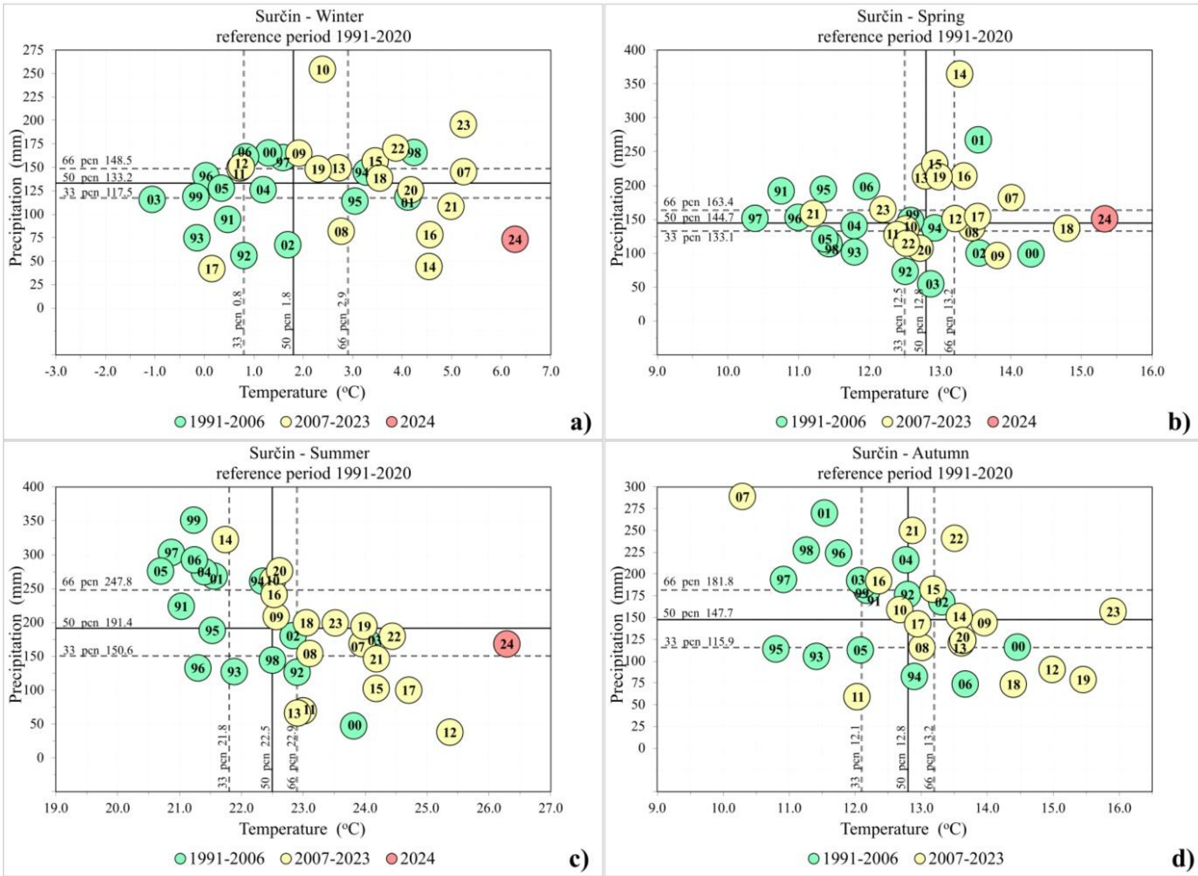

Figure 1. Mean seasonal air temperatures and total precipitation sums for winter (a), spring (b), summer (c), and autumn (d) and their corresponding terciles for Surčin, during the study period, compared to the reference period 1991–2020

The earliest onset of fruit ripening (RP) was recorded in 2024 (DOY: 229), occurring when spring and summer air temperatures exceeded the upper tercile threshold, while precipitation remained at normal levels in spring and approached the lower tercile in summer (Fig. 1b and c). Conversely, the latest RP (DOY: 319) was recorded in 2011, a year characterized by significantly below-lower-tercile temperatures and precipitation in spring, along with slightly above-upper-tercile summer temperatures and significantly below-lower-tercile precipitation. No fruiting occurred in 2023 due to an abrupt cessation of flowering caused by snowfall and low temperatures in early April, with maximum temperatures below the reference normal values for this period (1991–2020), and a record-breaking snow depth since the start of measurements (RHMS). Given the substantial influence of flowering timing on fruiting outcomes, flowering phenophases were documented in 2024. Between 2007 and 2024, the earliest BF (DOY: 57) was recorded, occurring 6 days earlier than any previously recorded onset and 43 days earlier than the latest recorded date within this 17-year period (Ocokoljić et al., 2023). Full flowering was observed on DOY 64, with flowering concluding on DOY 82 in 2024. A comparative analysis with previous studies (Ocokoljić et al., 2023) indicates that the flowering in 2024 concluded 16 days earlier than the earliest flowering onset during 2007–2023. Considering that the earliest flowering onset was recorded in 2024 (DOY: 57), a graph illustrating daily air temperatures for February and March 2024, within the flowering phenophase, along with reference normals from 1991–2020, is presented in Figure 2.

It was confirmed that the flowering period of the studied blackthorn population occurred unusually early, placing it at risk of damage from spring frosts. Consequently, the graphs of mean monthly air temperatures and monthly precipitation for March and April during the study period (2007–2024) were prepared for comparison with the reference period (1991–2020) (Fig. 3a and 3b). The March temperatures were significantly above the upper tercile with precipitation at normal levels, while April showed the temperatures significantly above the upper tercile and precipitation below the lower tercile. Between 2007 and 2024, the average fruit ripening period spanned 288 days in the phenological fruiting cycle, with the shortest ripening period recorded in 2024 on August 14. Figure 3c illustrates that in July 2024, the air temperatures were significantly above the upper tercile and precipitation was slightly above this threshold, whereas in August (Fig. 3d), the temperatures remained significantly above the upper tercile and precipitation fell significantly below the lower tercile.

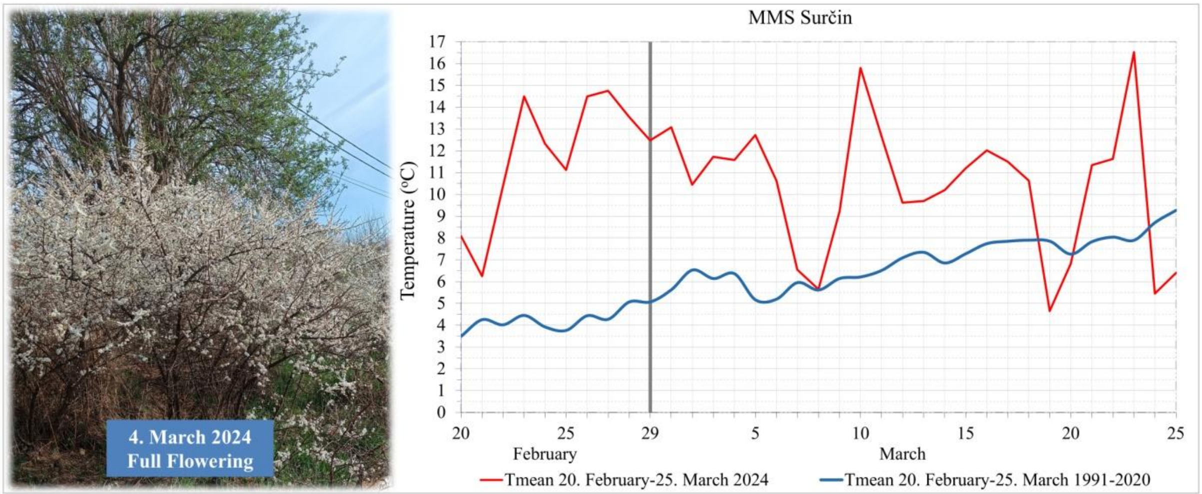

Figure 2. Blackthorn in full flowering phase on March 4, 2024, within the research area, alongside the mean daily air temperatures for February and March 2024 compared to the reference normals from 1991–2020 (data from GMS Surčin)

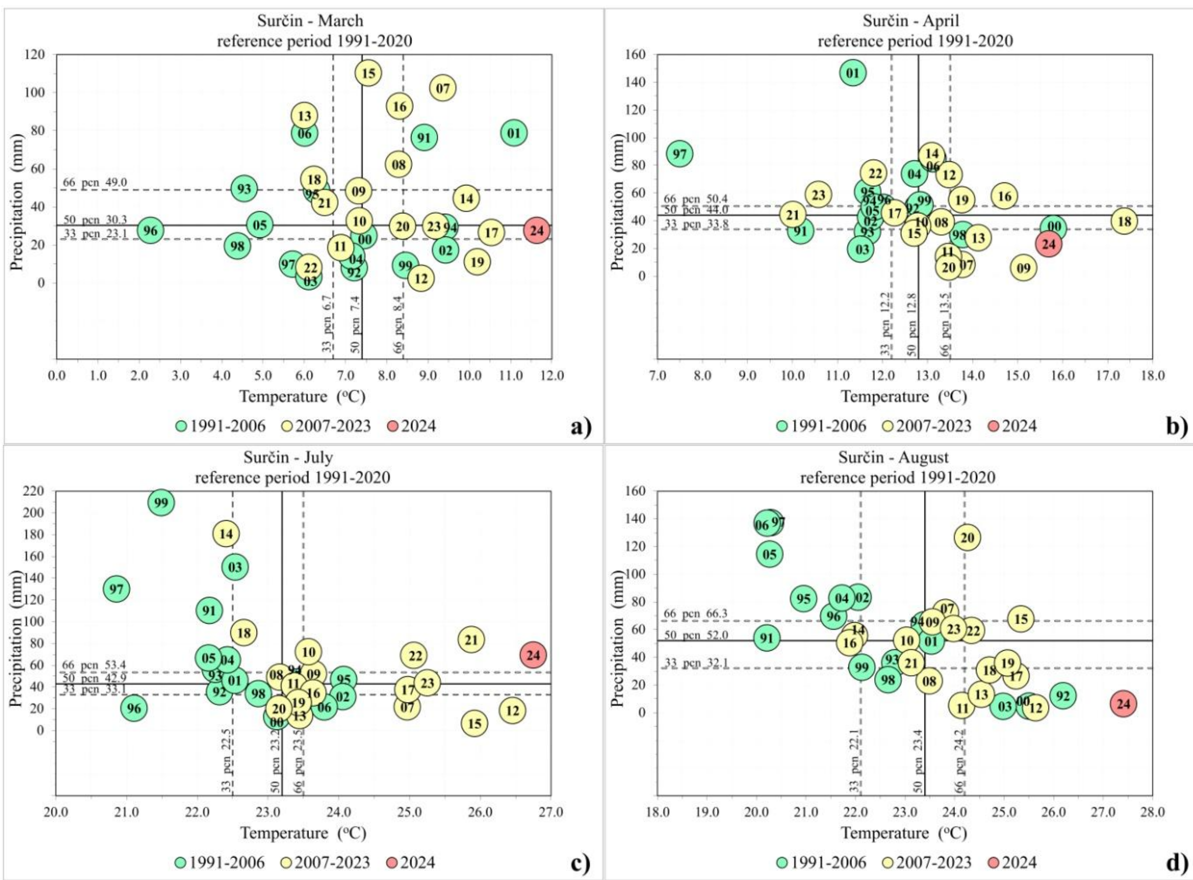

Figure 3. Mean monthly air temperatures and total precipitation for March (a), April (b), July (c), and August (d), with corresponding terciles for Surčin, during the study period (2007–2024), compared to the reference period (1991–2020)

Significant decreasing trends in RP DOY and RP GDD were identified (Fig. 4 and 5). The linear trends of the phenological fruiting pattern are negative (declining) and statistically significant (Mann-Kendall trend test values: S = -61, Z = -2.4737 and S = -64, Z = -2.5951), confirming a statistically significant shift towards earlier fruit ripening and lower accumulated heat for fruit ripening, indicating their dependence on climatic parameters. For RP, the accumulated heat sums ranged from 2,697.6°C (2024, DOY: 227) to 3,333.2°C (2012, DOY: 296), with an average accumulated heat of 3075.0°C over the period 2007–2024. While GDD varied throughout the study period, it exhibited a clear decreasing trend independent of DOY. Therefore, a comparative analysis of temperature, precipitation, and insolation is warranted (Tab. 1).

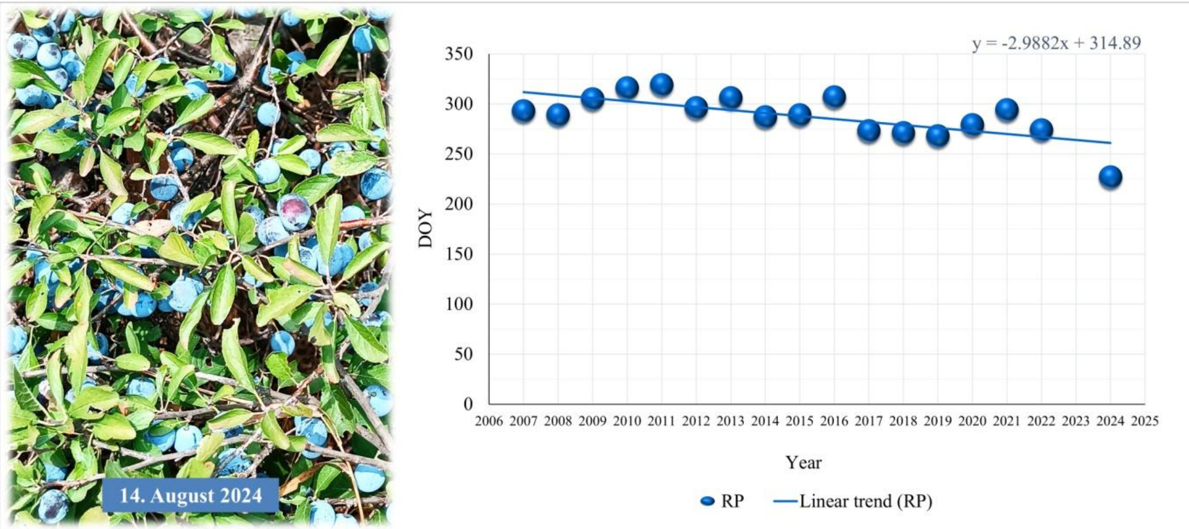

Figure 4. DOY for the fruit ripening dates (RP) in the period 2007–2024, with a linear trend representation of the observed blackthorn phenophase

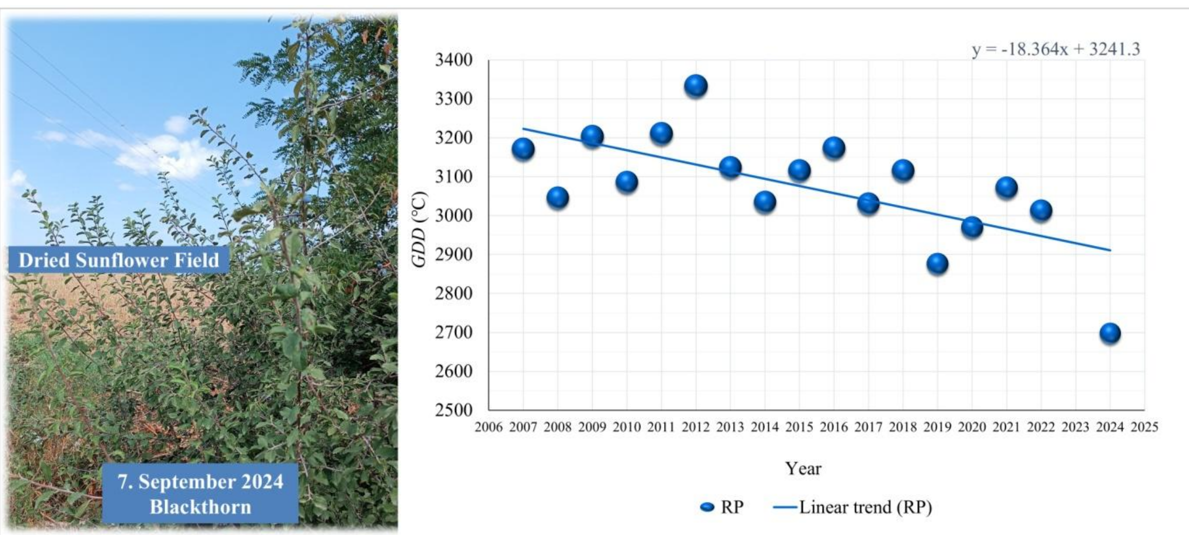

Figure 5. GDD for the fruit ripening dates (RP) in the period 2007–2024, with a linear trend representation of the observed blackthorn phenophase

Table 1. Descriptive statistics for the parameters of blackthorn phenological patterns and climatic variables in the period 2007–2024, from January 1st to the RP date

	RP DOY	**RP *GDD***	**T_{sr}***	**$T_{sr\ max}$**	**$T_{sr\ min}$**	**RR**	**SS**
Min	227	2697.6	13.6	18.5	8.4	339.5	1546.7
Max	319	3333.2	16.5	21.8	10.9	809.6	2034.7
Sum	4893	52275	254.1	343.4	162.2	8458.1	31055
Mean	287.82	3075	14.947	20.2	9.5411	497.53	1826.8
Std. error	5.3407	34.711	0.1645	0.1804	0.1432	30.993	33.203
Variance	484.90	20477	0.4601	0.5537	0.3488	16329	18741
Stand. dev	22.020	143.97	0.6783	0.7441	0.5906	127.78	136.89

Median	289	3086.4	15	20.2	9.5	495.1	1826.7
25 prcntil	273.5	3021.9	14.7	19.85	9.15	380.25	1737.5
75 prcntil	305.5	3172.3	15.25	20.7	9.9	555.75	1953.6
Skewness	-1.143	-0.948	-0.042	-0.196	0.4666	0.9253	-0.056
Kurtosis	2.5108	2.2590	1.5334	1.3997	0.9012	0.8425	-0.421
Geom. mean	286.97	3071.7	14.932	20.187	9.5241	483.23	1821.9
Coeff. var	7.6501	4.6536	4.5384	3.6838	6.1907	25.681	7.4938

Legend: *Mean air temperature (T_{sr}), mean maximum air temperature ($T_{sr\ max}$), mean minimum air temperature ($T_{sr\ min}$), total precipitation (RR), and total sunshine hours (SS)

The standard deviation and other measures of deviation indicate shifts in fruit ripening and fluctuations in climatic elements. This is further confirmed by Spearman's correlation coefficients, which show a significant negative correlation between RP DOY and RP *GDD* with T_{sr}, $T_{sr\ max}$, and $T_{sr\ min}$, indicating that as temperatures increase, DOY decreases, leading to earlier occurrences of key phenological events with reduced accumulated heat. Other correlation coefficients were not significant. The findings of this study align with WMO (2021) projections that anticipate warmer and drier summers, warmer and wetter winters, as well as increased summer droughts and extended growing seasons. Our research confirms the phenological stability of blackthorn, contrasting with nearby species (e.g. Atlas cedar, Chinese arborvitae, sunflower plantation, etc.), which exhibited signs of drought stress in the summer of 2024. These findings are critical for formulating guidelines within the landscape context of green infrastructure, aiming to foster a sense of place by predicting future changes in biodiversity, ecosystem functioning, and by enhancing ecosystem services and adaptability in peri-urban environments (Sjöman et al., 2016).

CONCLUSION

Phenological patterns show a strong correlation with climatic elements, underscoring their value in assessing the vulnerability and adaptability of species to climate change. The results obtained confirm the plasticity of blackthorn's flowering and fruiting phases, emphasizing their role in key functional traits associated with resilience to rising temperatures, drought, and increased sunshine hours. These data, combined with an understanding of functionality, can guide the selection of plants for green infrastructure in peri-urban environments to enhance resilience against future climate changes. Such efforts support sustainable development objectives for metropolitan peripheries, alongside the conservation and restoration of biodiversity essential for both nature and human well-being.

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