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COMPARATIVE ANALYSIS OF VEGETATIVE AND PHENOLOGICAL DEVELOPMENT OF PLUM CULTIVARS 'ANDREEA', 'RECORD', AND 'ČAČANSKA LEPOTICA' GRAFTED ON MIROBOLAN

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ABSTRACT
This study investigates the vegetative and phenological development of three plum cultivars ('Andreea', 'Record', and 'Cacanska lepotica') grafted on Mirobolan rootstock. Trunk diameter, annual shoot length and number, trunk cross-sectional area, and the budburst and flowering phenophases were monitored over a three-year period. The results highlight significant differences among cultivars: 'Record' showed rapid growth and early flowering, 'Andreea' exhibited slower growth and prolonged flowering, while 'Cacanska lepotica' displayed intermediate characteristics. The integrated analysis indicates varying adaptability of the cultivars to local climatic conditions and underscores the importance of selecting cultivars based on vegetation timing. The study provides valuable data for orchard management and for optimizing plum production.

INTRODUCTION

The plum (*Prunus domestica* L.), one of the most important fruit species in temperate regions, is widely cultivated for the production of fruit intended for fresh consumption, processing, and drying. In the current context of climate change, biotic pressures, and market demands, research on plum is increasingly taking diverse, interdisciplinary directions (Petri et al., 2018). Botu et al. (2007) mention that the main traditional fruit trees cultivated in Romania are the European plum (*Prunus domestica* L.). An important line of work is genetic improvement for resistance to diseases, tolerance to drought, salinity, extreme temperatures, and adaptability to varied soils (Zhebentyayeva et al., 2019). Conventional breeding programs are complemented by modern methods such as genetic engineering, molecular markers, and marker-assisted selection (Scorza et al., 2013). Strong emphasis is also placed on studying genetic resources and the diversity of traditional and local cultivars, to conserve genetic heritage and capitalize on traits such as taste, nutritional quality, and stress resilience (Sotille et al., 2022). Plum germplasm is analyzed using state-of-the-art genomic methods (Zhebentyayeva et al., 2019). Another active area of research concerns rootstocks and their influence on the growth, fruiting, and quality of grafted trees. Rootstock–scion compatibility, vigor, yield, expressed by indicators such as TCSA (trunk cross-sectional area), and productive efficiency are aspects frequently analyzed in multiannual experiments (Kajtár-Czinege et al., 2024; Ling et al., 2025). Overall, modern research directions in plum clearly reflect a shift toward integrated approaches, genetic, ecological, technological, and commercial, aimed at both sustainable production and the maximization of the economic value of plum cultivation. The present study aims to analyze the performance of several plum cultivars grown in Craiova, focusing on their growth characteristics and the unfolding of vegetative phenophases, aspects that may be useful for future research.

MATERIAL AND METHODS

Text The biological material consisted of three plum cultivars, 'Andreea', 'Record', and 'Cacanska lepotica', grafted onto Mirobolan and grown in the experimental field of the Banu Maracine Research Station, Craiova. Growth characteristics and the progression of vegetative phenophases were analyzed, with data collected in 2022–2023, 2023–2024, and 2024–2025.

To determine the growth characteristics of the analyzed cultivars, the following measurements were performed: two perpendicular trunk diameters were measured at the graft union, at 5 cm above the graft and at 5 cm below the graft, and the mean of the two diameters was used to capture any possible trunk deformations or ovalization, a method also used by Ungureanu et al., 2022; additionally, the number and length of annual shoots were recorded.

The trunk cross-sectional area (TCSA) in cm2 was calculated from trunk diameter using the classical formula TCSA = π·(D/2)2, where D is the diameter in cm, taken as the mean of the two perpendicular diameters measured 5 cm above the graft union. Many authors use this calculation (Faber et al., 2002; Glisic et al., 2015; Kumar et al., 2019), and others employ this index to estimate fruit yield and other parameters (Chapman et al., 1986).

The annual growth increment was quantified using the formula:

ΔTCSA = TCSAt − TCSAt−1 (Glisic et al., 2015).

For recording the different phenophases, the BBCH scale was used (Meier, 2001).

RESULTS AND DISCUSSIONS

Text Measuring trunk diameter at different positions is an essential indicator of growth vigor and scion–rootstock compatibility in fruit tree species. In plum, evaluating these parameters allows assessment of how the rootstock influences scion development and the stability of the graft union in the early years of growth.

The objective of the measurements was to analyze variability in diameter at the graft union, 5 cm above, and 5 cm below it, during the first three years after planting, for three plum cultivars: 'Andreea', 'Record', and 'Cacanska lepotica' grafted on the Mirobolan rootstock.

These measurements aimed to: highlight differences in growth vigor among cultivars; assess the uniformity of tree development through the coefficient of variation (CV%); and evaluate scion–rootstock compatibility based on the relationship between the diameters measured above and below the graft union. The results are presented in Table 1.

Table 1

Diameter variability at the graft union, 5 cm below, and 5 cm above in plum cultivars grafted on Mirobolan

Cultivar/Descriptive statistics		Diameter at the grafting point (mm)			Diameter at 5 cm above the grafting point (mm)			Diameter at 5 cm below the grafting point (mm)		
		An 1	An 2	An 3	An 1	An 2	An 3	An 1	An 2	An 3
'Andreea'	Medie	42,06	44,50	46,13	27,18	29,50	31,50	37,29	39,00	41,38
	Min	34,05	36,00	38,50	19,89	21,00	23,50	28,77	30,00	32,50
	Max	48,79	50,00	52,50	32,48	34,00	36,00	41,60	43,00	45,00
	CV %	14,65	4,65	5,65	21,44	2,81	17,00	17,44	13,94	10,98
'Record'	Medie	57,50	59,75	61,88	45,25	47,75	49,63	55,41	57,25	59,25
	Min	51,51	53,00	75,50	43,71	45,00	47,00	48,28	50,00	52,50
	Max	64,74	66,00	68,50	47,29	49,00	51,00	67,79	69,00	71,50
	CV %	9,00	8,09	7,15	3,75	5,13	4,23	14,52	7,34	11,38
'Cacanska lepotica'	Medie	57,17	59,50	61,13	63,16	65,50	67,88	55,40	57,50	59,38
	Min	47,06	49,00	51,00	39,77	41,00	43,00	42,99	44,00	46,50
	Max	63,37	65,00	67,50	54,06	56,00	58,00	64,47	66,00	68,50
	CV %	12,82	4,46	10,44	13,71	10,27	11,59	16,21	2,82	16,84

Regarding the diameter at the graft union, the following were observed: the cultivar 'Andreea' showed a substantial increase in diameter at the graft union compared with its values in 2022–2023, with a relatively high coefficient of variation in the first year (CV 14.65 %); 'Record' displayed the highest absolute values in all years, being a very vigorous cultivar, with moderate variability in diameter at the graft union (CV between 7–9 %); 'Cacanska lepotica' recorded values close to 'Record', but slightly lower in 2024–2025. The cultivars 'Record' and 'Cacanska lepotica' had significantly larger diameters than 'Andreea', indicating higher vigor. Year-to-year increases are evident in all cultivars, confirming steady development.

Regarding the diameter measured 5 cm above the graft union, in the cultivar 'Andreea', the parameter values increased significantly, but the significant coefficient of variation suggests differences among trees. In 'Record', very high mean diameter values were recorded across the three analyzed years, namely 45.25 mm, 47.75 mm, and 49.63 mm, with a low coefficient of variation of 3.75–5.13%, indicating high uniformity for the 5 cm diameter above the graft union in this cultivar. The cultivar 'Cacanska lepotica' showed a higher coefficient of variation for this parameter compared with the other two cultivars. 'Record' stood out for the most excellent uniformity, evidenced by a low coefficient of variation and large diameters 5 cm above the graft union, which indicates excellent compatibility with the rootstock and high vigor of the scion portion.

Regarding the 5 cm diameter below the graft union, the most significant values were recorded in 'Record', especially in 2024–2025, with a small coefficient of variation, indicating uniform development.

Analyzing the variability of diameter at the graft union, as well as 5 cm above and below it, in the plum cultivars 'Andreea', 'Record', and 'Cacanska lepotica' grafted on the Mirobolan rootstock, significant differences among genotypes are evident in terms of vigor and uniformity of annual growth.

The cultivar 'Record' was distinguished by the highest mean diameter values at all measurement points and in all three years of observation. At the same time, the reduced coefficient of variation (CV%) between 3.75 % and 9 % indicates high uniformity of trees, confirming the excellent compatibility between 'Record' and the Mirobolan rootstock.

The cultivar 'Cacanska lepotica' also showed high diameter values, very close to those of 'Record', but with slightly greater variability, especially in the third year (CV up to 16.84 %). This suggests good vigor and steady growth, but with somewhat more pronounced differences among individuals.

By contrast, 'Andreea' showed the smallest diameter values at all measurement stages. Although year-to-year growth was evident, the lower values and higher coefficients of variation (up to 21.44 %) reflect reduced vigor and more pronounced non-uniformity. These results may be attributable to weaker adaptation to the Mirobolan rootstock or to genetic particularities of the cultivar.

Additionally, the analysis of differences between the diameters measured above and below the graft union indicates good bonding between scion and rootstock in the cultivars 'Record' and 'Cacanska lepotica', whereas in 'Andreea' these differences were more pronounced, suggesting slightly lower compatibility.

Based on the data presented in Table 1, it can be concluded that the cultivar 'Record' grafted on Mirobolan exhibited the greatest growth vigor, the best uniformity of diameters, and the best compatibility with the rootstock. The cultivar 'Cacanska lepotica' ranked second, with close results, demonstrating balanced growth and harmonious development, though with slightly greater variability among individuals. The cultivar 'Andreea' showed slower growth and lower uniformity, indicating overall reduced vigor and a possibly weaker adaptation to the Mirobolan rootstock.

In conclusion, among the analyzed cultivars, 'Record' proved to be the top performer in trunk diameter growth during the first three years of vegetation and is the most recommended for grafting onto the Mirobolan rootstock under the analyzed conditions.

To complete the assessment of growth vigor in the three plum cultivars grafted on Mirobolan, the length of annual shoots was also measured over the three years of observation. This indicator provides additional information on the regenerative capacity and vegetative potential of the cultivars and is closely correlated with the trunk diameter values analyzed above.

The results are presented in Figure 1, which highlights differences among cultivars in terms of the rate and intensity of vegetative growth. It can be observed that the cultivar 'Record' consistently showed the highest annual shoot growth, confirming the high vigor also evidenced by the trunk diameter analysis. It stood out through rapid and uniform year-to-year growth, indicating good adaptation to the Mirobolan rootstock and superior vegetative capacity.

The cultivar 'Cacanska lepotica' occupied an intermediate position, with values close to 'Record' in the first and second year, but with a slight decrease in the growth rate in the third year. This trend suggests moderately high vigor, albeit slightly influenced by growing conditions or the cultivar's physiological characteristics.

The cultivar 'Andreea' recorded the smallest annual shoot lengths, with differences evident from the first year and maintained through the end of the study period. This behavior reflects lower vigor and reduced compatibility with the Mirobolan rootstock, as supported by the lower trunk diameters reported earlier.

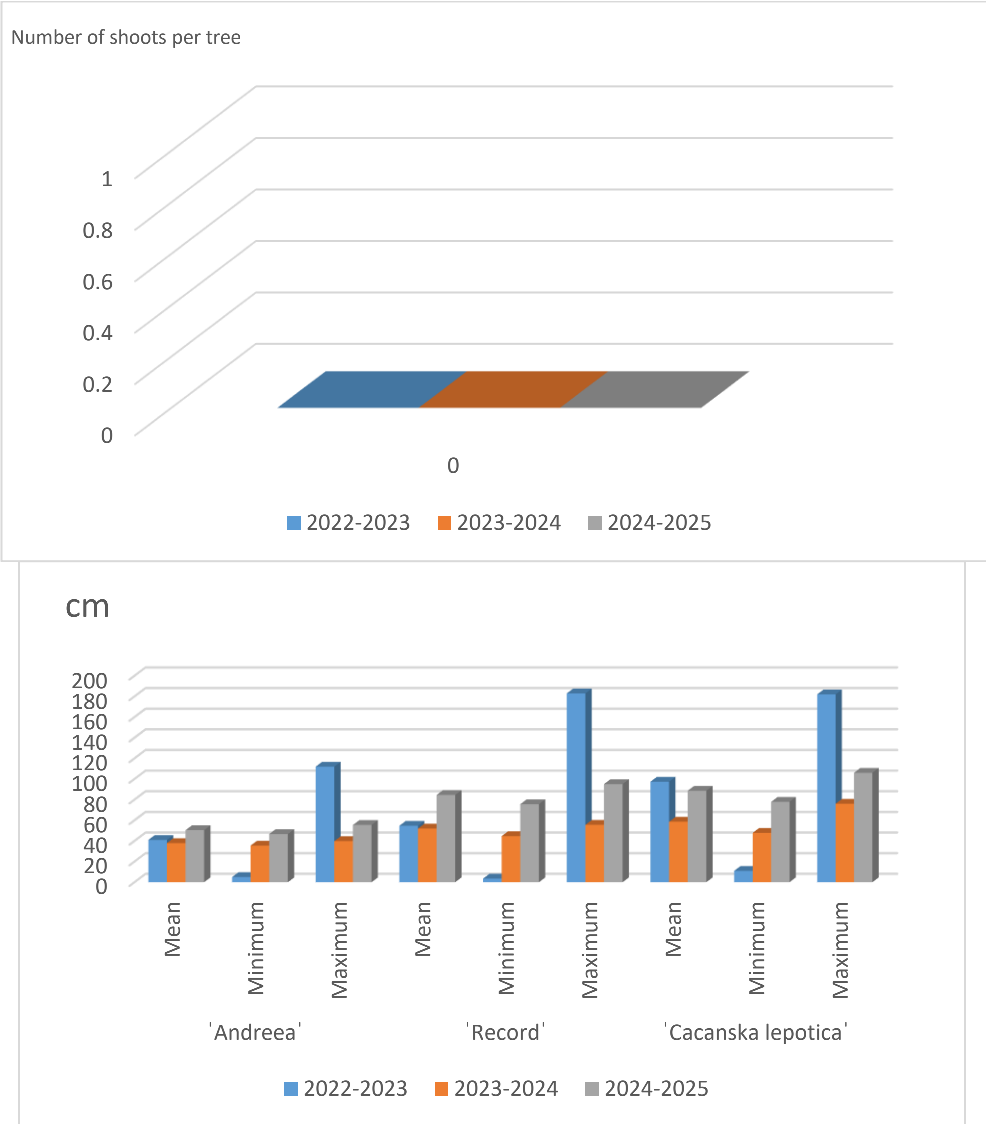

Figure 1. Number of shoots per tree and annual shoot length in the three plum cultivars

Based on the data in Figure 1, 'Record' exhibited the highest vegetative growth capacity, followed by 'Cacanska lepotica', while 'Andreea' showed significantly reduced growth. The graph highlights a progressive year-to-year increase in the minimum, mean, and maximum number of shoots per tree for all three cultivars analyzed, with consistently higher values recorded for ‘Record’ and ‘Čačanska Lepotica’ compared to ‘Andreea’. The results confirm the trend observed in the diameter analysis, showing a positive correlation between annual shoot length and trunk diameter, reflecting the harmonious development of the vegetative system in the more vigorous cultivars.

Table 2

Correlations Between Different Characteristics of Plum Cultivars Grafted on Myrobalan

Characteristics	*GD*	*UD*	*LD*	*NS*	*SL*
Graft union diameter (GD)	1				
Diameter 5 cm above the graft (UD)	0,85	1,00			
Diameter 5 cm below the graft (LD)	0,99	0,87	1,00		
Number of annual shoots/tree (NS)	0,98	0,73	0,97	1,00	
Length of annual shoots (SL)	0,87	1,00	0,89	0,76	1,00

To highlight the relationships between the morfhological parameters of the grafting area and the dynamics of vegetative growth, correlations were calculated, and the results are presented în the table 2. This highlights very strong positive correlations between the graft union diameter and the diameters measured 5 cm above and below it, as well as with the number and length of annual shoots, suggesting a structural and physiological interdependence between the thickness of the graft union and the growth vigor of plum cultivars grafted on Myrobalan.

The determination of trunk cross-sectional area (TCSA) is a fundamental indicator for assessing growth vigor in fruit trees, reflecting the accumulation of woody biomass and the development of the vegetative system over time. In the same vein, the annual increment of TCSA reflects the year-to-year dynamics of trunk diameter. It is directly correlated with physiological activity and the degree of adaptation of the cultivar to the rootstock.

These determinations aimed to compare the growth rate of the three plum cultivars ('Andreea', 'Record', and 'Cacanska lepotica') grafted on the Mirobolan rootstock during 2022–2025, by analyzing the evolution of TCSA and its annual increment.

The results are presented in Table 3. They illustrate differences among cultivars in woody mass accumulation and the pace of vegetative development, and confirm the previously observed trend: 'Record' grafted on Mirobolan stands out for the highest growth vigor, both in trunk cross-sectional area and in annual increment. The trajectory of values indicates steady, sustained development, with an exponential increase in the third year of vegetation.

'Cacanska lepotica' showed good vigor, close to 'Record', but with a lower intensity of increment in the last interval analyzed, suggesting a slight stabilization of vegetative growth. By contrast, 'Andreea' showed clearly lower values for both TCSA and annual increment, confirming reduced vigor and a more modest adaptation to the Mirobolan rootstock.

Table 3

Trunk cross-sectional area (cm^2) and annual increment (cm^2) in the analyzed plum cultivars (average/cultivar)

Cultivar	**2022-2023**	**2023-2024**	**2024-2025**	**Growth increment 2023-2024**	**Growth increment 2024-2025**
'Andreea'	5.80	6.83	7.79	1,03	0,96
'Record'	16.07	17.90	19.34	1,83	1,44
'Cacanska lepotica'	31.31	33.68	36.17	2,37	2,49

In conclusion, among the cultivars analyzed, 'Record' stood out as the most vigorous and best-adapted, exhibiting the most significant accumulation of woody biomass and the best growth dynamics throughout the study period. The high values of this parameter in the third study years may also be due to the application of drip irrigation and root-applied fertilizers (farmyard manure and NPK 15-15-15 complexes) at a rate of 100 kg/ha, as well as foliar fertilizers (Cropmax 0.2 %). Glišić et al. (2023) reported that all plum genotypes analyzed in western Serbia exhibited low vigor. The vigor of fruit trees and vegetative growth is generally indicated by trunk diameter size (Zanfir & Baciu, 2020a; Zanfir & Baciu, 2020b; Zanfir & Baciu, 2021).

The study of developmental phenophases is an essential element in the biological characterization of fruit cultivars, providing valuable information on the timing of budbreak and their behavior in relation to climatic conditions. The vegetative budbreak phenophase is particularly important, as it marks the beginning of annual physiological activity and directly influences subsequent phenology (flowering, shoot growth, fruiting).

Table 4 presents data on the progression of phenological phases corresponding to BBCH stages 01–34 for the cultivars 'Andreea', 'Record', and 'Cacanska lepotica' in the years 2023–2024 and 2024–2025.

Table 4

Vegetative budbreak in the analyzed plum cultivars

Phenophase	**'Andreea'**		**'Record'**		**'Cacanska lepotica'**	
	2023-2024	**2024-2025**	**2023-2024**	**2024-2025**	**2023-2024**	**2024-2025**
BBCH01					26.03	01.04
BBCH03	27.03	01.04	26.03	01.04	03.04	07.04
BBCH09	4.04	07.04	03.04	07.04		
BBCH10	10.04	14.04	09.04	14.04	10.04	14.04
BBCH11	13.04	17.04	14.04	17.04	13.04	17.04
BBCH32	25.04	29.04				
BBCH33			26.04	29.04		
BBCH34					24.04	29.04

The data show moderate temporal differences among the analyzed cultivars in the onset and progression of vegetative budbreak phases.

In 2023–2024, the cultivars 'Andreea' and 'Record' showed earlier budbreak, with the first phenological phase (BBCH 03 – swollen buds) observed around March 26–27. In the case of 'Cacanska lepotica', budbreak was slightly delayed, with the first signs recorded on April 3 (BBCH03), indicating a more late-budding character for this cultivar.

The early phases of full budbreak (BBCH09–BBCH10) occurred between April 3–10, with relatively good synchronization among cultivars, and the appearance of the first leaves (BBCH11) occurred between April 13–14, concluding by April 17.

In 2024–2025, the phenophases generally occurred 3–5 days later than in the previous year, which may correlate with a better start to spring. All cultivars reached stage BBCH 10 (beginning of full budbreak) around April 14, indicating better synchronization among genotypes in the second year of observation. In the study conducted by Corneanu et al. (2022), budbreak (BBCH 01) occurred between 07.03–11.03 and between 25.03–05.04, depending on the cultivar and the climatic year.

The analysis of budbreak phenophases shows earlier vegetation onset for the cultivars 'Andreea' and 'Record', and later budbreak for 'Cacanska lepotica'. Overall, 'Record' stood out for its steady, balanced pace of development and its good adaptation to climatic conditions in both study years. 'Andreea' had a quick start but a shorter progression of phenophases, whereas 'Cacanska lepotica' showed slower yet uniform development. The results confirm apparent genetic differences among cultivars in phenological dynamics, an essential aspect for establishing optimal cultural practice timing and assessing the risk of late-spring frost damage.

The phenophases associated with the onset and progression of inflorescences are biologically important stages in fruit tree development, directly influenced by climatic conditions and the genetic characteristics of the cultivar. The timing of flowering plays a significant role in determining the risk posed by late frosts and in synchronizing pollination and fertilization. Rising temperatures drive changes in the relative duration of vegetative phenophases and in the frequency of thermal stress. Therefore, adaptation strategies to climate change should focus on the use of drought-tolerant cultivars and on adjusting phenology to the new environmental conditions to avoid extreme events (Cosmulescu et al., 2010a; Cosmulescu et al., 2010b).

Table 5 presents data on the onset and progression of phenological phases corresponding to flowering (BBCH 56–72) for the three plum cultivars grafted on Mirobolan in the observation years 2023–2024 and 2024–2025. The data analysis reveals notable differences among cultivars regarding the timing of floral bud appearance and the duration of flowering.

Table 5

Onset and progression of inflorescences in the analyzed plum cultivars

Phenophase	**'Andreea'**		**'Record'**		**'Cacanska lepotica'**	
	2023-2024	**2024-2025**	**2023-2024**	**2024-2025**	**2023-2024**	**2024-2025**
BBCH56	09.04		05.04	01.04	04.04	
BBCH57	11.04		07.04		06.04	01.04
BBCH60	12.04	01.04	10.04.		09.04	
BBCH64				07.04		
BBCH65	19.04		18.04		17.04	07.04
BBCH67	26.04	07.04	25.04	14.04	23.04	
BBCH69	05.05	14.04	04.05	17.04	03.05	14.04
BBCH71				29.04		17.04
BBCH72		29.04				29.04

In 2023–2024, the cultivar 'Record' exhibited early flowering, with the onset of BBCH56 (visible flower buds) on April 5, followed by BBCH65 (full flowering) on April 18 and BBCH69 (end of flowering) on May 4. The cultivar 'Andreea' started later, with the first inflorescences observed on April 9 and the end of flowering around May 5, suggesting a more extended flowering period.

In 'Cacanska lepotica', phenophases were generally slightly delayed compared with 'Record', with full flowering occurring around April 17 and its end around May 3, placing it among mid-season cultivars.

In 2024–2025, phenophases occurred earlier, especially in 'Record' and 'Cacanska lepotica', where full flowering (BBCH65) was recorded between April 7 and 14, and the end of flowering (BBCH69) between April 14 and 17. This 7–10-day advance relative to the previous year may be correlated with a more favorable thermal regime in spring 2025, which accelerated floral bud development.

By contrast, in 'Andreea' in 2024–2025, the data show a slight delay in phenophase onset, which could indicate a more sensitive response to climatic variability or lower vigor in resuming the vegetative cycle. Glišić et al. (2023) reported that all plum genotypes analyzed in western Serbia have a long flowering period and late flowering.

Based on the results, it can be concluded that 'Record' stood out for earlier, more concentrated flowering, a favorable trait for efficient pollination and uniform fruit set. 'Cacanska lepotica' showed mid-season flowering over a moderate period, indicating good adaptation to climatic conditions. 'Andreea', by contrast, was characterized by later and more prolonged flowering, which could increase sensitivity to unfavorable weather (rain, wind, or low temperatures during flowering).

Overall, the dynamics of flowering phenophases confirm the biological particularities of each cultivar and highlight the influence of annual climatic conditions on the pace of phenological development. Differences in the onset of phenological phases among cultivars depend on the rootstock, a fact confirmed by many authors (Sestras et al., 2007; Botu et al., 2007; Cosmulescu et al., 2010a; Cosmulescu et al., 2010b).

CONCLUSIONS

The integrated analysis of vegetative and phenological characteristics of the three plum cultivars highlights apparent genetic differences in growth and development dynamics. The cultivar 'Record' stood out through rapid growth, early and concentrated flowering, and a steady onset of vegetation, indicating good adaptation to the climatic conditions. 'Andreea' exhibited slower growth but a prolonged flowering period and rapid budbreak, whereas 'Cacanska lepotica' was characterized by a moderate pace of vegetative and phenological development, with mid-season flowering. Overall, the observed differences among cultivars can guide their selection and management in orchards according to growth timing, resilience to climatic conditions, and production goals.

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