

ASSESSMENT OF DIFFERENT PLUM CULTIVAR RESPONSES TO LATE SPRING FROST IN NORTH-EAST OF TRANSYLVANIA

EVALUAREA RĂSPUNSULUI DIFERITELOR SOIURI DE PRUN LA ÎNGHEȚURILE TÂRZII DE PRIMĂVARĂ ÎN NORD-ESTUL TRANSILVANIEI

ZAGRAI Luminița Antonela¹, ZAGRAI Ioan^{1*} VLAȘIN Larisa Daniela¹,
GUZU Georgeta Maria¹, MOLDOVAN Claudiu¹

*Corresponding author e-mail: izagrai@yahoo.com

Abstract.

Late spring frosts represent a major threat to plum orchards, especially to early-flowering cultivars, with the risk amplified by climate changes. In spring 2025, six consecutive days of negative temperatures caused varying damage to reproductive organs. A study conducted on two experimental plots monitored 35 Romanian and foreign plum cultivars exposed to frost, with data analyzed using *k*-means and PCA. Cultivars were classified into four groups: very sensitive, sensitive, tolerant, and resistant, with direct effects on yield. The results provide a scientific basis for recommending frost-tolerant or resistant cultivars as a practical strategy to stabilize production in areas prone to late spring frosts.

Key words: plum, cultivars, risk, late spring frost, resistance

Rezumat.

Înghețurile târzii de primăvară reprezintă o amenințare majoră pentru culturile de prun, mai ales pentru soiurile cu înflorire timpurie, riscul fiind amplificat de schimbările climatice. În primăvara 2025, șase zile consecutive cu temperaturi negative au provocat daune variabile formațiunilor de rod. Un studiu realizat pe două loturi experimentale a vizat monitorizarea a 35 de soiuri de prun, românești și străine, expuse la îngheț, iar datele au fost analizate prin *k*-means și PCA. Soiurile au fost clasificate în patru grupe: foarte sensibile, sensibile, tolerante și rezistente, cu efect direct asupra producției. Rezultatele oferă o bază științifică pentru recomandarea soiurilor tolerante sau rezistente la îngheț, ca strategie practică de stabilizare a producției în zonele afectate de înghețuri târzii.

Cuvinte cheie: prun, soiuri, risc, înghețuri târzii de primăvară, rezistență

¹ Fruit Research & Development Station Bistrița, Romania

INTRODUCTION

Frost injuries represent a major limiting factor in the cultivation and geographic distribution of horticultural species, particularly in temperate regions. Despite extensive research efforts, frost continues to cause greater economic losses in fruit and vegetable production than any other environmental or biological stressor. Furthermore, the physiological and molecular mechanisms underlying cold hardiness are still not fully elucidated [Rodrigo, 2020].

The plum is a widely cultivated stone fruit species in temperate climates, highly valued for its substantial genetic diversity. In Romania, the European plum (*Prunus domestica* L.) represents the most important fruit species, ranking second globally in plum production after China, and holding the leading position in Europe [FAOSTAT, 2025].

Climate change projections indicate potential constraints on the growth, productivity, and spatial distribution of many economically important plant species, including members of the *Prunus*. Climate changes influence plant dynamics, manifesting as phenological shifts in response to vulnerable environmental conditions. Consequently, phenological phases have advanced and, in some cases, shortened in duration. In certain regions, this advancement increases the risk of frost damage to actively growing tissues [Milošević and Milošević, 2023]. In plum, recent observations from the temperate continental climate of Romania reveal variations in flowering phenology, with several cultivars, including ‘Centenar’, ‘Anna Späth’, ‘Minerva’, and ‘Stanley’, exhibiting an earlier onset of blooming compared to previous records [Gitea *et al.*, 2019].

Some cultivars exhibit susceptibility to abiotic stress factors, particularly to late spring frosts. The frost constitutes one of the most critical threats to plum crops, directly impacting flower buds viability, with influence on fruiting potential [Muffler *et al.*, 2016]. The frost sensitivity of flower buds is closely linked to intensity and duration of the frost [Milošević and Milošević, 2023] and to their phenological stage. During the flowering period, reproductive organs are extremely vulnerable, often resulting in severe injuries and reduced yield potential. The risk of damage caused by frost increases significantly in genotypes that bloom and set fruit early [Muffler *et al.*, 2016]. Moreover, late spring frosts occurring a few days before or during budburst appear to be decisive for tree survival and overall fitness, as they coincide with the phase of minimal freezing resistance and an almost absent reacclimatization capacity [Vitra *et al.*, 2017]. According to a recent study, late spring frost can significantly delay phenology by reducing photosynthetic activity by 13.6%. This type of climatic event may consequently lower photosynthetic productivity in the year following its occurrence [Wang *et al.*, 2025].

Plum belongs to the category of early-flowering species; therefore, its generative organs exhibit sensitivity to late spring frosts. Flowers at the white bud stage (BBCH 57-59) can withstand temperatures down to -4.9°C , while open flowers tolerate temperatures as low as -3.2°C . Flower resistance may increase up

to -6°C if several days of low temperatures occur prior to flowering. Among the floral organs, the pistil is the most sensitive to frost, followed by the ovary. Fruit set is damaged at temperatures around -1.1°C [Mitre, 2002]. According to Murray [2020], the extent of damage to fruit trees resulting from late spring frosts is determined not only by the severity of the critical temperatures and the phenological stage of the trees at the time of the frost event, but also by the duration of exposure to these temperatures. For instance, during the white bud to petal emergence stage in plum, damage was estimated at 10% at -3.3°C , increasing to 90% at -5.5°C [Murray, 2020].

The frost tolerance of plum cultivars is closely linked to their geographical origin and breeding region. Cultivars from Western Europe typically exhibit low to moderate frost resistance, as seen in cultivars such as ‘Reine Claude Verte’ and ‘d’Agen’, whereas cultivars originating from North America and China, including ‘Opata’, ‘Sapa’, and ‘Waneta’, demonstrate significantly higher frost tolerance [Sestraš, 2004].

This study aimed to assess the behavior of different plum cultivars under the ecological conditions of northeastern Transylvania, with particular focus on their response to late spring frosts and their overall frost resistance in the context of ongoing climate changes.

MATERIAL AND METHOD

Experimental field plots

The present study was carried out within two experimental plum trials at the Fruit Research and Development Station (FRDS) Bistrița. The first trial was initiated in 2020 on Myrobalan 29C rootstock, while the second one was established in 2021, on St. Julien rootstock. Together, these trials comprise a collection of over 35 plum cultivars, representing both indigenous and foreign genetic resources. The majority of cultivars under investigation are of Romanian origin, reflecting the valuable plum breeding heritage of the country (e.g., ‘Diana’, ‘Centenar’, ‘Carpatin’, ‘Tuleu gras’, ‘Minerva’, ‘Agent’, ‘Flora’, ‘Gras ameliorat’, ‘Andreea’, ‘Matilda’, ‘Elena’, ‘Delia’, ‘Zamfira’, ‘Iulia’, ‘Jubileu 50’, ‘Ivan’, ‘Doina’, ‘Țița’, ‘Pescăruș’, ‘Silvia’, ‘Tuleu dulce’, and ‘Zandra’). Alongside these, several foreign cultivars are also included, some of them widely cultivated and well recognized at European level (‘Joganta’, ‘Jofela’, ‘Tophit’, ‘Topper’, ‘Topend plus’, ‘Top five’, ‘Jojo’, ‘Anna Späth’, ‘Stanley’, ‘President’, ‘Reine Claude d’Althan’, ‘Blue free’, and ‘French improved’). By bringing together both Romanian cultivars and foreign plum cultivars, the trials provide a broad comparative framework for assessing their adaptation to the ecological conditions of northeastern Transylvania, as well as their susceptibility to late spring frosts in the context of climate change.

Sampling method

Flower bud sampling was conducted 10 days after the frost event to accurately assess the impact of late spring frost on plum cultivars. From each plum cultivar, one hundred of flower buds were randomly collected from three representative trees, ensuring that the samples reflected the overall variability within the experimental plot.

The flower buds were then examined to determine the proportion exhibiting frost damage, providing a quantitative measure of frost sensitivity for each cultivar. Additionally, fruit yield was assessed at harvest maturity and expressed as kilograms per tree, based on the average production recorded from six trees per cultivar.

Monitoring of climatic factors and extreme weather events

The evaluation of climatic stress effects on plum cultivars requires continuous monitoring of multiple risk indicators relevant for this species, including late spring frosts, winter frosts exceeding the species' resistance threshold, hailstorms, strong winds, low temperatures, precipitation and cloud cover during flowering, significant temperature fluctuations during the growing season, drought during fruit development, heat stress, and other abiotic factors.

At the FRDS Bistrița, climatic parameters are monitored using an automated weather station (Adcon Telemetry) equipped with AGROEXPERT software, which ensures continuous recording, storage, and analysis of air temperature, relative humidity, precipitation, and other meteorological variables of interest.

Although several climatic stress factors are systematically monitored, the present study focuses specifically on the impact of late spring frosts that occurred between April 6th and 11th, 2025. During this period, the plum cultivars were found in different phenological stages, ranging from green bud (56 BBCH for stone fruits) and white bud (57–59 BBCH), to beginning of flowering (60–62 BBCH) [Meier *et al.*, 2001]. These phenological differences are of particular importance, since the sensitivity of floral organs to frost varies greatly depending on the developmental stage. As a result, the recorded frost event provided a natural framework for evaluating the variability in frost susceptibility among the studied cultivars under real field conditions.

Statistical analyses

K-means clustering was performed to classify the data into four distinct clusters based on similarity in extent of floral organ damage, by comparing within and between group variances. The analysis was conducted with the following parameters: clustering criterion determinant (W), stop conditions iterations = 500, and convergence = 0.00001.

Principal component analysis (PCA) biplot was performed using values of BBCH scale for stone trees, flower bud load, and average yield as variables, in correlation with 35 plum cultivars classified with k-means. The k-means clustering and PCA analysis were conducted using software XLSTAT 2019.3.2.62913.

RESULTS AND DISCUSSIONS

Extreme weather events

During the analyzed period (Table 1), a sequence of frost events was recorded, with minimum air temperatures ranging between -0.7°C (April 10th) to -5.2°C (April 7th) over six consecutive days. The average daily temperature dropped below 0°C in three out of six days (April 7th, 8th, and 11th), indicating conditions highly unfavorable for phenological development of fruit trees in the spring of 2025. Relative humidity fluctuated between 54.9% to 83.9%, with higher values on two days. These, in relation with light precipitation, created an environment conducive to ice formation on flower buds and flowers. Precipitation occurred

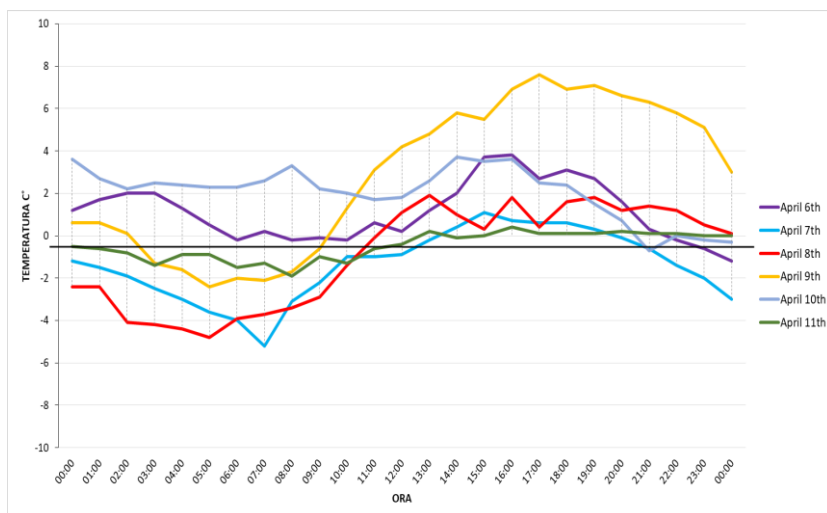
almost daily, with values between 0.8 mm to 2.2 mm, could amplify the risk of frost injury, especially under alternating freeze–thaw conditions.

Table 1

Weather data recorded during the frost period at FRDS Bistrița (2025)

Date	Temperature (°C)			Average relative humidity (%)	Precipitation (mm)
	Minimum	Maximum	Average		
April 6 th	-1.2	4.3	1.1	69.4	1.6
April 7 th	-5.2	1.1	-1.4	54.9	0.0
April 8 th	-4.8	2.0	-0.9	78.8	0.8
April 9 th	-2.4	7.9	2.8	62.3	0.0
April 10 th	-0.7	4.4	2.0	59.5	2.2
April 11 th	-1.9	0.4	-0.5	83.9	1.2

The persistence of negative temperatures for six consecutive nights for 2-12 hours (Figure 1) in the period of April, 6th-11th, 2025, sometimes combined with high humidity and intermittent rainfall, highlights the severity of this frost episode and its potential to cause significant damage to sensitive reproductive organs of plum cultivars at FRDS Bistrița.

**Fig. 1.** Hourly temperature during the frost period of April 6th-11th, 2025

Plum cultivar responses to the spring frost events

The evaluation of plum cultivars at FRDS Bistrița during the April 2025 frost episode revealed distinct differences in their sensitivity to low temperatures, highlighting the genetic variability within the collection.

The k-means clustering analysis, based on extent of floral organ damage, allowed the classification of the 35 genotypes into four distinct clusters (Table 2). The first cluster/class included 14 cultivars, within-class variance was 26.44, and the average distance to centroid was 3.90. Taking into consideration these parameters and its large number of objects/cultivars, this cluster can be considered

relatively cohesive. Second cluster/class included 10 cultivars and was characterized by lower within-class variance (17.88), and also by lower average distance to centroid (3.08), indicated that it was the most compact and homogeneous of all groups. The third cluster included 7 cultivars and exhibited the highest within-class variance (37.24) together with the largest average distance to centroid (4.61) suggesting a high degree of heterogeneity, despite of the smaller object number. The last one cluster/class exhibited no within-class variance and zero distances to centroid, suggesting that these 4 genotypes are nearly identical, forming an extremely uniform cluster.

Table 2

Class	1	2	3	4
Objects	14	10	7	4
Sum of weights	14	10	7	4
Within-class variance	26.44	17.88	37.24	0.00
Minimum distance to centroid	0.14	0.10	1.28	0.00
Average distance to centroid	3.90	3.08	4.61	0.00
Maximum distance to centroid	8.86	10.10	11.71	0.00

1. Frost-highly sensitive cultivars

Cluster 1 included **fourteen frost-highly sensitive cultivars**, which suffered extreme damage with significant loss of generative organs, particularly affecting the pistil, which is the most frost-sensitive floral organ and critical for successful fruit set. This large group of cultivars (Table 3) exhibited very high flower bud mortality (83–100%), independent of their initial flower bud load. Cultivars such as ‘Black Sun’, ‘Jojo’, ‘Andreea’, ‘French improved’, ‘Zamfira’, ‘Jofela’, ‘d’Agen’, ‘Topper’, ‘Flora’, ‘Zandra’, and ‘Diana’, recorded over 90% flower bud damage (Figure 2), resulting in negligible or very low yields (0–5 kg/tree). Also, several plum cultivars, such as ‘Agent’, ‘Tita’ and ‘Reine Claude d’Althan’, exhibited severe frost injury, with flower bud damage ranging from 83% to 85%. As a consequence, the fruit yield was considerably reduced, reaching only to 0.2-4 kg per tree (Figure 3).

Table 3

Cultivar	BBCH scale for stone fruits	Flower bud load	Flower bud damaged by frost (%)	Average yield (kg/tree)
Black Sun	59	Normal	100	0
Jojo	59-60	High	99	0.4
Andreea	59	Normal	96	0.3
French improved	56	Low	95	0
Zamfira	59	Normal	93	5
Jofela	56	Low	91	0
d’Agen	59	Normal	90	0.1

Topper	59	Normal	90	3.8
Flora	56	Low	90	0.5
Zandra	56	Low	90	0.3
Diana	59	Normal	90	2.1
Agent	59	Normal	85	0.2
Tita	56-57	Normal	84	4
Reine Claude d'Althan	56	Normal	83	0.9



Fig. 2. Plum cultivars highly susceptible to frost, with bud damage exceeding 90%



Fig. 3. Plum cultivars susceptible to frost, with flower bud damage level of 83-85%

2. Frost-sensitive cultivars

Cluster 2 comprised **ten frost-sensitive cultivars**, which showed severe damage with low to moderate values of yield. Among the widely cultivated plum cultivars, 'Tophit', 'Anna Späth', 'Stanley', and 'President' recorded frost damage levels of 65–70%, reflecting a considerable susceptibility to low-temperature stress (Table 4). Similar patterns of injury were also observed in Romanian cultivars, such as 'Pescăruș', 'Minerva', 'Ivan', 'Tuleu dulce', 'Carpatin', and 'Silvia', exhibiting their vulnerability under severe frost conditions. Figure 4 presents representative plum cultivars from this group, which exhibited notable levels of frost susceptibility

(damage level of 58-72%). The cultivars from cluster 2 exhibited low or very low yields (0.4-7.5 kg/tree).

Table 4

Frost-sensitive cultivars				
Cultivar	BBCH scale for stone fruits	Flower bud load	Flower bud damaged by frost (%)	Average yield (kg/tree)
Pescăruș	56	Normal	72	5.2
Minerva	59	Normal	72	5.3
Tophit	56	Normal	70	2.4
Anna Spăth	56	Normal	70	1.6
Stanley	56	Normal	70	0.9
Ivan	59	Normal	70	0.7
Tuleu dulce	56	Normal	68	1.1
Carpatin	56	Low	66	0.4
President	59	Normal	65	7.5
Silvia	59-61	Normal	58	1.9



Fig. 4. Plum cultivars susceptible to frost, with flower bud damage level of 58-72%

3. Frost-tolerant cultivars

Cluster 3 contained **seven frost-tolerant cultivars** which maintained a relatively acceptable fruiting potential despite exposure to low temperatures. Intermediate frost responses (Table 5) were observed in cultivars such as ‘Iulia’, ‘Toppend plus’, ‘Top five’, ‘Gras ameliorat’, ‘Delia’, ‘Doina’, and ‘Joganta’, which exhibited flower bud damage ranging from 33% to 50% (Figure 5). Although all these cultivars experienced partial losses due to frost, considerable differences were observed in their resulting yields. Notably, ‘Iulia’ recorded a remarkable fruit yield of 33.6 kg per tree, maintaining near-normal production even when 50% of the flowers were damaged. Similarly, ‘Toppend plus’ and ‘Top five’ combined a high fruiting potential with partial frost tolerance, producing substantial yields despite significant flower bud damage (19.1 kg/tree, respectively 16.1 kg/tree). By contrast, cultivars such as ‘Joganta’, ‘Doina’, ‘Gras ameliorat’, and ‘Delia’ exhibited low or

very low yields (0.2-6.2 kg/tree) under similar frost conditions, likely due to a lower fruit set. These results indicate a relative tolerance to frost among the cluster 3 cultivars and highlight their suitability for cultivation under conditions prone to low-temperature stress.

Table 5

Frost-tolerant cultivars				
Cultivar	BBCH scale for stone fruits	Flower bud load	Flower bud damaged by frost (%)	Average yield (kg/tree)
Iulia	56-59	Normal	50	33.6
Toppend plus	56	Normal	50	19.1
Top five	59	Normal	49	16.1
Delia	59-60	Normal	46	0.2
Gras ameliorat	56	Normal	43	6.1
Doina	60-61	Normal	42	1
Joganta	56	Normal	33	6.2



Fig. 5. Plum cultivars tolerant to frost, with flower bud damage level of 33-50%

4. Frost-resistant cultivars

In contrast, cluster 4 grouped **four frost-resistant cultivars**, which exhibited minimal or no injury on generative organs while preserving a very good capacity for fruit set. Thus, several plum cultivars including ‘Elena’, ‘Centenar’, ‘Jubileu 50’, and ‘Blue free’ showed no flower bud damage, demonstrating a remarkable level of frost resistance. Interestingly, in the case of ‘Centenar’, minor injuries were observed on the stamens, while the pistil and ovary remained completely unaffected (Figure 6). This selective organ-specific tolerance allowed successful fruit set and development, contributing to the cultivar’s high productivity despite partial floral organ injury.

Among the four cultivars, ‘Elena’ and ‘Centenar’, both exhibiting a normal flower bud load, recorded high yields of 19 kg and 20 kg per tree, respectively, highlighting their potential as reliable cultivars for regions prone to spring frosts

(Table 6). Although ‘Jubileu 50’ and ‘Blue free’ were also unaffected by frost, their relatively low flower bud load constrained the total fruit yield, illustrating that frost resistance alone does not always guarantee maximal productivity.

Overall, among all cultivars studied, ‘Elena’ and ‘Centenar’ displayed the optimal combination of frost resistance and high productivity, making them particularly suitable for cultivation in frost-prone areas. Notably, the ‘Iulia’ cultivar, classified in the frost-tolerant group, recorded the highest yield among all 35 genotypes evaluated, despite experiencing partial flower bud damage. Additionally, the cultivar ‘Toppend Plus’, also classified within the frost-tolerant group, achieved a yield comparable to that of ‘Elena’ and ‘Centenar’. Importantly, three of these four cultivars (‘Centenar’, ‘Elena’, and ‘Iulia’) are the result of Romanian breeding programs, which confers particular significance both in terms of agronomic performance and in strengthening the national fruit-growing heritage. These findings emphasize their dual role as valuable genetic resources for future breeding efforts and as reliable options for orchard establishment in regions where late spring frosts remain a critical limiting factor for plum production.



Fig. 6. Plum cultivars resistant to frost

Table 6

Frost-resistant cultivars				
Cultivar	BBCH scale for stone fruits	Flower bud load	Flower bud damaged by frost (%)	Average yield (kg/tree)
Elena	56	Normal	0	20
Centenar	59-60	Normal	0	19
Jubileu 50	56-59	Low	0	0.7
Blue free	56	Low	0	1.2

Principal Component Analysis of frost response and agronomic traits in plum cultivars

Figure 7 presents a biplot derived from principal component analysis (PCA), illustrating the distribution of 35 plum cultivars based on three variables. The PCA explained 85.03% of the total variance in the dataset (50.38% F1 and 34.65% F2). The biplot highlights the relationship between the variables (the BBCH scale for stone fruits, flower bud load, and average yield), plum cultivars being classified according to frost-induction susceptibility.

F1 axis is associated with flower bud load and BBCH scale, showing that cultivars with normal or high flower bud load generally were in an advance

phenology stage. The F2 axis is more strongly correlated with average yield, showing a tendency toward higher yield performance.

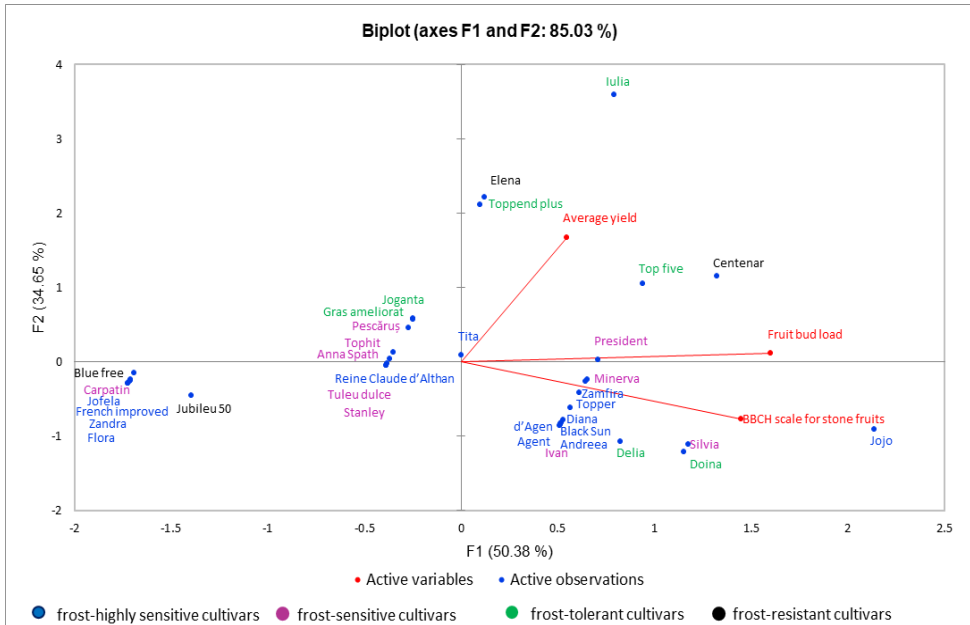


Fig. 7. PCA of 35 plum cultivars and flower bud damage by frost, BBCH scale for stone fruits, flower bud load and average yield correlation

Frost-highly sensitive cultivars (blue) are clustered mostly in the lower right quadrant (e.g. 'Jojo', 'Zamfira', 'Topper', 'Diana', 'Black Sun', 'd' Agen', 'Agent', and 'Andreea'), being strongly associated with moderate values of average yield, advanced phenological stage and normal flower bud load, with the exception of 'Jojo', which exhibit a high flower bud load. Other cultivars, such as: 'Jofela', 'French improved', 'Zandra', and 'Flora' were characterized by low flower bud load, early phenological stage and low average yield. A normal flower bud load and early phenological stage were observed for 'Tita' and 'Reine Claude d'Althan', however 'Tita' cultivar showed moderate value yield. Overall, these cultivars proved to be the most sensitive to frost- induce flower bud damage, which was largely correlated with early phenology stages and low flower bud load.

Frost-sensitive cultivars (magenta): 'Pescaruș', 'Tophit', and 'Anna Spăth' were grouped closer to the origin, indicating moderate performance across variables without strong association to extreme traits. In contrast, 'Tuleu dulce', and 'Stanley' were associated with low average yield, all being susceptible to frost. 'Minerva', 'President' 'Ivan' and 'Silvia' cultivars had showed advanced phenological stages correlated with frost sensitive, however only 'Minerva' and 'President' exhibited moderate values for average yield. 'Carpatin' cultivar was negatively correlated with all variables.

Frost-tolerant cultivars (green): ‘Joganta’ and ‘Gras ameliorat’ cultivars were in an early phenological stage directly correlated with tolerance to frost, and moderate values for average yield. Cultivars from upper right quadrant (‘Toppend plus’, ‘Iulia’, and ‘Top five’) had showed the highest average yield, and distinct phenology stages with low degree of flower bud frosted. In contrast ‘Delia’ and ‘Doina’ cultivars despite their advanced phenology stage, normal flower bud load and low values for yield, had showed low flower bud damaged by frost.

Frost-resistant cultivars (black): ‘Elena’ and ‘Centenar’ are located in the positive F1/F2 quadrant, characterized by normal flower bud load and higher values of average yield, even the ‘Centenar’ cultivar were in an advance phenology stage, did not showed flower bud damaged. ‘Blue free’ and ‘Jubileu 50’ cultivars were positioned on the negative side of F1/F2 and were characterized by low flower bud load directly correlated with low average yield values, and early phenological stage.

The PCA highlights clear associations between frost tolerance and phenological status, flower bud load and average yield traits in plum cultivars. The biplot thus provides a useful classification tool for cultivar selection in frost-prone environments.

The frost episode acted as a strong differentiating factor, clearly separating cultivars into four resilience categories. Frost-highly sensitive cultivars suffered complete or almost complete reproductive loss, frost-sensitive cultivars exhibiting significant sensitivity to low temperature stress, while frost-tolerant cultivars displayed an intermediate performance. Frost-resistant genotypes preserved both bud viability and substantial yields when flower bud load was adequate.

These results underline the importance of selecting frost-resistant or tolerant cultivars such as ‘Centenar’, ‘Elena’, ‘Iulia’ and ‘Toppend Plus’ for sustainable plum production in frost-prone areas.

Previous studies provide further evidence of the differential response of plum cultivars to spring frost. Dimitrova et al. [2021] reported that cultivars such as ‘Stanley’ and ‘Tophit Plus’ sustained only minor injuries to flower buds and pistils, suggesting a relatively higher tolerance to low temperatures. In contrast, ‘Toptaste’, ‘Topgigant Plus’, and ‘Topper’ proved highly sensitive, with frost damage ranging from 59.6% to 75.8% at -3°C . Similarly, Butac [2020] found that exposure to temperatures between -1.7°C and -3.4°C induced 70–80% flower bud mortality in the cultivars ‘d’Agen’ and ‘Anna Späth’.

Other studies have shown that although during three consecutive years of late spring frosts negative temperatures were recorded on only one day, plum cultivars exhibited variable responses [Nesheva and Bozhkova, 2021]. During the first spring frost episode, plum cultivars were at beginning of flowering, a high degree of frost damage was recorded for ‘Toptaste’ (51%), ‘Topking’ (30%), and ‘Bellamira’ (20%) cultivars at -2.8°C . The lowest damage was observed in ‘Tophit plus’, ‘Cacanska Najbolja’, and ‘Stanley’ cultivars, with approximately 11% of flower buds affected. During the second spring frost episode, the plum cultivars

were not affected at -2.8°C . During the third spring frost episode, cultivars were in full bloom or in the flowering-fading stage and the temperature recorded was -5°C . Complete frost damage (100%) was observed in ‘Jojo’, ‘Pacific’, ‘Sirma’, ‘Pagane’ cultivars, and the plum hybrid HL 20-30. The lowest damage was recorded in ‘Tita’ cultivar (6%), followed by the ‘Stanley’ cultivar (12%). Low frost damage was also observed in ‘Top First’, ‘Toptaste’, ‘Topstar Plus’, ‘Robelle’, and ‘Piteștean’ cultivars.

The analysis of our field data from 35 plum cultivars, assessed across phenological stages, revealed only minor differences in frost damage between the green bud stage and the white bud/beginning of blooming (Figure 8).

Specifically, the incidence of damage was 61.9% at the green bud stage and 67.3% at the white bud/beginning of bloom stage, a difference of only 5.4% between the two stages. These values suggest that under conditions of severe and prolonged frost, with minimum temperatures reaching -5.2°C and remaining below freezing for six consecutive days, early floral stages do not benefit from significant protection against frost damage. Thus, the intensity and persistence of low temperatures proved decisive, reducing the sensitivity differences between phenophases.

This categorization provides valuable insights for both breeding programs and practical recommendations to growers, especially under the increasing frequency of late spring frosts associated with climate change.

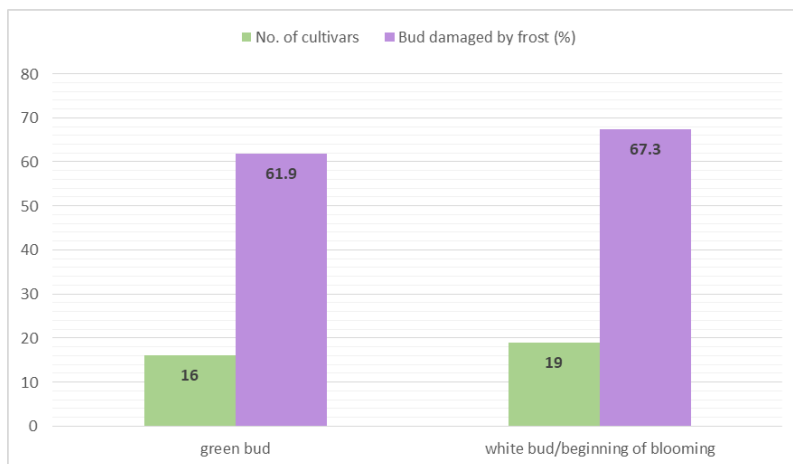


Fig. 8. Phenological stages in relation to frost damage

CONCLUSIONS

The comprehensive assessment of 35 plum cultivars under spring frost stress revealed pronounced genotypic variability in flower bud survival and yield

stability. Responses ranged from highly sensitive cultivars, exhibiting near-total flower bud mortality, to resistant genotypes that preserved reproductive potential and maintained satisfactory production levels. Multivariate analyses (cluster analysis and PCA) enabled the classification of cultivars into four distinct groups (highly sensitive, sensitive, tolerant, and resistant), thus providing a robust methodological framework for discriminating frost-resilience levels within germplasm collections.

Particularly, cultivars such as ‘Centenar’, ‘Elena’, ‘Iulia’, and ‘Toppend plus’ combined frost resistance or tolerance with acceptable yield performance, underscoring their suitability for cultivation in frost-prone environments. These findings not only contribute valuable insights for breeding programs aimed at enhancing resilience to abiotic stress but also support the strategic selection of cultivars for sustainable plum production under changing climatic conditions.

ACKNOWLEDGMENTS

This study is part of the two projects: ADER 6.3.4/2023 funded by the Ministry of Agriculture and Rural Development and CDI-ASAS 2183/2023 funded by the Academy of Agricultural and Forest *Gheorghe Ionescu-Șișești*.

REFERENCES

1. **Butac M., 2020** - *Plum breeding*. In: *Prunus*. IntechOpen, <http://dx.doi.org/10.5772/intechopen.92432>
2. **Dimitrova S., Krumov S., Sotirov D. Kolev, M., 2021** - *Response of some plum cultivars to abiotic stress*. *Acta Hort.* 1322, 201-208. <https://doi.org/10.17660/ActaHortic.2021.1322.29>
3. **Gitea M.A., Gitea D., Tit D.M., Purza L., Samuel A.D., Bungău S., Badea G.E., Aleya L., 2019** - *Orchard management under the effects of climate change: Implications for apple, plum, and almond growing*. *Environmental Science and Pollution Research*, 26(10), 9908-9915. <https://doi.org/10.1007/s11356-019-04214-1>
4. **Meier U., Bleiholder H., Weber E., Lancashire P., Feller C., Buhr L., Hess M., Strauss R., 2001** - *Growth stages of mono- and dicotyledonous plants*. BBCH monograph, 158, 20180906-074619.
5. **Milošević N., Milošević T., 2023** - *Impact of climate change on plum (Prunus domestica L.)*. In *Cultivation for Climate Change Resilience, Volume 2* (pp. 257-278). CRC Press.
6. **Mitre V., 2002** - *Specialized fruit growing (in Romanian)*. Academic Press, Cluj-Napoca.
7. **Muffler L., Beierkuhnlein C., Aas G., Jentsch A., Schweiger A.H., Zohner C., Kreyling, J., 2016** - *Distribution ranges and spring phenology explain late frost sensitivity in 170 woody plants from the Northern Hemisphere*. *Global Ecol. Biogeogr.*, 25, 1061-1071. <https://doi.org/10.1111/geb.1246>
8. **Murray M., 2020** - *Critical temperatures for frost damage on fruit trees*. https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1643&context=extension_cural
9. **Nesheva M., Bozhkova V., 2021** - *Spring frost damages of plum and apricot cultivars grown in the region of Plovdiv, Bulgaria*. *Scientific Papers. Series B, Horticulture*, LXV(1), 194-197.

10. **Rodrigo, J., 2020** - *Spring frosts in deciduous fruit trees - morphological damage and flower hardiness*, *Scientia Horticulturae*, 85(3),155-173, [https://doi.org/10.1016/S0304-4238\(99\)00150-8](https://doi.org/10.1016/S0304-4238(99)00150-8).
11. **Sestraș R., 2004** - *Ameliorarea speciilor horticole* (The Breeding of Fruit Growing Species). Academic Press.
12. **Vitra A., Lenz A. Vitasse Y., 2017** - *Frost hardening and dehardening potential in temperate trees from winter to budburst*. *New Phytol*, 216, 113-123. <https://doi.org/10.1111/nph.14698>
13. **Wang J., Hua H., Guo J., Huang X., Zhang X., et al., 2025**. *Late spring frost delays tree spring phenology by reducing photosynthetic productivity*. *Nat. Clim. Chang.*, 15, 201–209. <https://doi.org/10.1038/s41558-024-02205-w>
14. **FAOSTAT, 2025** - *Food and Agriculture Organization of the United Nations* (FAOSTAT) online: <https://www.fao.org/faostat/en/#data> (accessed on August 8th, 2025).