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THE INFLUENCE OF CLIMATIC CONDITIONS ON THE PHENOLOGICAL DYNAMICS OF INDIGENOUS AND LOCAL GRAPEVINE GENOTYPES IN SOUTHERN OLTENIA

Băjenaru Maria-Florentina[1,2], Stoenescu Ana-Maria[2*], Șerban Maria-Diana[2], Giugea Nicolae[3]

[1]Doctoral School of Plant and Animal Resources Engineering, Faculty of Horticulture, University of Craiova, 13 A.I. Cuza Street, Craiova, Romania
[2] Dăbuleni Research and Development Station for Plant Cultivation on Sandy Soils, 217 Petre Baniță Street, Călărași, Romania
[3]University of Craiova, Faculty of Horticulture, 13 A.I. Cuza Street, Craiova, Romania
* *Correspondence author. E-mail*: mariaciuca92@yahoo.ro

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ABSTRACT

This study presents results obtained over a three-year period (2024–2026) concerning the evaluation of local grapevine genotypes cultivated under the pedoclimatic conditions of the Research and Development Station for Plant Cultivation on Sandy Soils in Dăbuleni (southern Oltenia, Romania). The experiment was established in a young vineyard trained on a trellis system, with a planting distance of 1.2 × 2.5 m and drip irrigation. The biological material included three indigenous genotypes ('Parmac', 'Berbecel', and 'Roșioară') and one local genotype ('Gălbioară'). The main phenological stages were monitored according to the BBCH scale. Phenological observations indicated a relatively uniform progression of the growth stages. During the study period, budburst occurred between April 3 and 14, flowering between May 19 and June 2, veraison between July 24 and August 10, and grape ripening between September 2 and 18, with variations observed among genotypes and years. The results contribute to the characterization and conservation of local grapevine germplasm and may support the identification of genotypes with enhanced adaptability to increasingly variable climatic conditions affecting viticulture.

INTRODUCTION

Vitis vinifera L. is one of the oldest perennial crops (Ghaffari & Ferchichi, 2011), whose vegetative cycle, morphologically described through phenological stages, is primarily determined by air temperature (Olteanu, 2000). Precipitation levels, soil properties, and solar radiation are also important factors, although to a lesser extent (Olteanu, 2000; Buciumeanu et al., 2018).

Climate change affects the onset and duration of each phenological stage, also influencing grape yield in both quantitative and qualitative terms (Ollat et al., 2016). In addition, climate change has a significant impact on viticulture by modifying the relationships between plants and pests, pathogens, and weeds, while reducing the time available to farmers to manage these challenges. These changes may also be driven by farmers' long-term responses to climate change (Bora et al., 2016).

The impact of spring frost on the productivity of vineyards depends on several factors, including the phenological stage at the time of the event, the intensity and duration of low temperatures, vineyard topography, and the genetic characteristics of the cultivated varieties. In recent years, earlier budburst, driven by warmer winters and springs, has increased grapevine vulnerability to late frost events, particularly in regions characterized by high interannual climatic variability. Consequently, identifying varieties or genotypes with greater resistance to climatic stress has become an important objective of modern viticulture (Dina et al., 2026).

Plant phenology is a frequently used means of environmental monitoring and a widely used bioindicator of climate change. The relationship between temperature and phenological stages, as evidenced by changes in their onset dates in recent years, makes phenology a relevant tool for anticipating the potential effects of climate change (Menzel et al., 2020).

Three main phenological stages are used to describe the developmental cycle of grapevine: budburst, flowering, and berry ripening. Early budburst exposes young leaves to a higher risk of damage from spring frost, and this risk is likely to increase in the future in certain viticultural regions (Sgubin et al., 2018). Berry ripening occurs under increasingly warmer conditions, which leads to reduced acidity at harvest (Duchêne et al., 2014; Sweetman et al., 2014), promotes sugar accumulation and the production of wines with a high alcohol content, and alters the accumulation of secondary metabolites (Lecourieux et al., 2014, 2017; Chedid et al., 2025).

Sandy soils in the arid areas of southern Romania have limited natural resources for the successful cultivation of conventional crops; therefore, they require crops capable of developing under conditions of limited resources and high temperatures throughout the growing season.

Previous studies have shown that some of the most suitable crops for these lands include Jerusalem artichoke, watermelon, pumpkin, tomato, grapevine, etc. (Dima et al., 2021; Nanu et al., 2024; Sfîrloagă et al., 2025; Frătuțu et al., 2026; Băjenaru et al., 2026).

The aim of this study is to evaluate the influence of climatic conditions on the phenological dynamics of local grapevine genotypes cultivated in the southern Oltenia region by analyzing key phenophases. The study seeks to highlight the relationships between variations in climatic factors specifically temperature and precipitation and the phenological response of the investigated genotypes, as well as to identify their specific adaptation characteristics regarding the area's pedoclimatic conditions.

MATERIAL AND METHODS

The research was conducted within the ampelographic collection of the Dăbuleni Research and Development Station for Plant Cultivation on Sandy Soils (RDSPCSS), located in Călărași, Dolj County, Romania, on the thirdterrace of the Danube River. The soil in the experimental area is a sandy eutric protosol with lamellar characteristics, with a pedological profile of Ap–Ac–C1–Cla.

The biological material consisted of local grapevine genotypes ‘Parmac’ (prime ‘Dimyat’ = ‘Coarnă Albă’ × ‘Heunisch Weiss’; VIVC code 5716), ‘Berbecel’ (VIVC code 1148), ‘Gălbioară’, as well as the ‘Roșioară’ (prime name ‘Pamid’, VIVC code 8899), cultivated on their own roots. The vineyard was established at a planting distance of 1.2 m between vines and 2.5 m between rows, corresponding to a

planting density of 3,333vines ha^{-1}.The study was conducted during the 2024–2026 period.

The experiment was arranged according to a randomized complete block design (RCBD), with three replicates for each genotype, each replicate consisting of three grapevines. The results represent the mean values of the three experimental replicates. Climatic data for the study years 2024–2026 were recorded using an iMetos weather station installed in the experimental field (Table 1). Observations were conducted daily, and the main climatic parameters were recorded, including mean, maximum, and minimum temperatures, precipitation amounts; the number of rainy days; and the number of days with maximum temperatures exceeding 30 °C. The global heat balance represents the sum of the daily mean temperatures recorded during the growing season (April 1 – September 30), whereas the active heat balance represents the sum of the daily mean temperatures exceeding the 10 °C threshold during the same period. The useful heat l balance represents the sum of the differences between the daily mean temperatures exceeding 10 °C and the biological threshold of 10 °C (Georgescu et al., 1986).

The experimental observations focused on grapevine phenology. The main phenological stages were monitored according to the BBCH scale, including budburst (BBCH 07–09), flowering (BBCH 61–69), berry growth (BBCH 71–79), veraison (BBCH 81), and full ripening (BBCH 89) (Figure 3), according to Meier (2001).

For comparative analysis, the date of occurrence of each phenological stage was converted to Day of Year (DOY), with January 1 corresponding to DOY 1. The duration of each phenological interval was calculated as the difference between the DOY values of two consecutive stages.

During the growing season, standard vineyard management practices were applied in accordance with the cultivation technology specific to the region. Preventive phytosanitarytreatments were carried out at the mainphenological stages, while soil maintenanceincluded mechanical operations, such asshredding plant residues, shallow soilcultivation, and weed control before budburst. Supplementary irrigation was provided using a drip irrigation system. Depending on seasonal conditions, four to five irrigation cycles were performed annually, with a water volume of 30.95 m^3/ha applied during each event.

RESULTS AND DISCUSSIONS

During the 2024–2026 study period, at the Dăbuleni Research and Development Station for Plant Cultivation on Sandy Soils, the evolution of climatic conditions was characterized by a high thermal regime and a deficient precipitation regime, typical of southern Oltenia. The mean annual temperature ranged from 12.18 to 14.52 °C, indicating a warm climate favorable for grapevine cultivation, with pronounced thermal extremes: the absolute maximum temperature reached 41.21 °C in July 2025, whereas the absolute minimum dropped to −16.5 °C in January 2026, reflecting a large thermal amplitude (Table 1).

The minimum temperatures, ranging from −12.9 °C to −16.5 °C during the 2024–2026 period, were favorable for grapevine overwintering under optimal conditions, with no bud losses recorded in the analyzed genotypes. This result suggests that, under the specific conditions prevailing during the study years, the local genotypes exhibited an adequate capacity to withstand the winter dormancy period.

Table 1.

Main climatic characteristics during the 2024–2026 period

Climatic elements	Year		
	2024	2025	2026
Mean temperature (°C)	14.52	12.98	12.18
Minimum temperature (°C)	-12.9	-13.32	-16.5
Maximum temperature (°C)	40.9	41.2	39.3
Global heat balance (Σ t°g)	3927	3709	3566
Active heat balance (Σ t°a)	3898	3683	3482
Useful heat balance (Σ t°u)	2098	1939	1752
Annual precipitation (mm)	511.9	357.8	685.4
Precipitation during the growing season (mm)	247.8	141.0	217.6
Number of rainy days	116	114	139
Number of days with maximum temperatures > 30 °C	99	91	72

Unprotected grapevine cultivation is possible in areas where absolute minimum winter temperatures range from −14 to −22 °C for wine grape varieties and from −14 to −24 °C for table grape varieties, provided that the occurrence of such temperature values does not exceed 1–2 years out of 10 (Oșlobeanu et al., 1980). However, grapevine tolerance to low temperatures depends not only on the minimum temperature reached, but also on the duration of exposure, the physiological stage of the plants, and the genetic characteristics of the cultivar (Ren et al., 2023; Londo & Kovaleski, 2025).

During the active growing season (April–September), mean monthly temperatures ranged from 12.1 °C in April 2026 to 26.5 °C in July 2024, providing highly favorable conditions for grapevine growth and berry ripening (Figure 1).

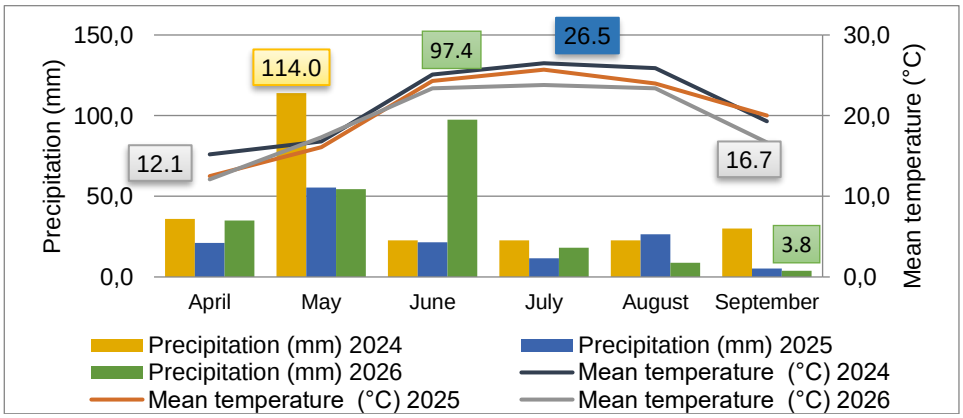


Figure 1. Climatic data for the growing season (2024–2026)

These values demonstrate the presence of favorable thermal conditions for the completion of the annual grapevine growth cycle, while also highlighting the crop's exposure to extreme temperatures during the growing season.

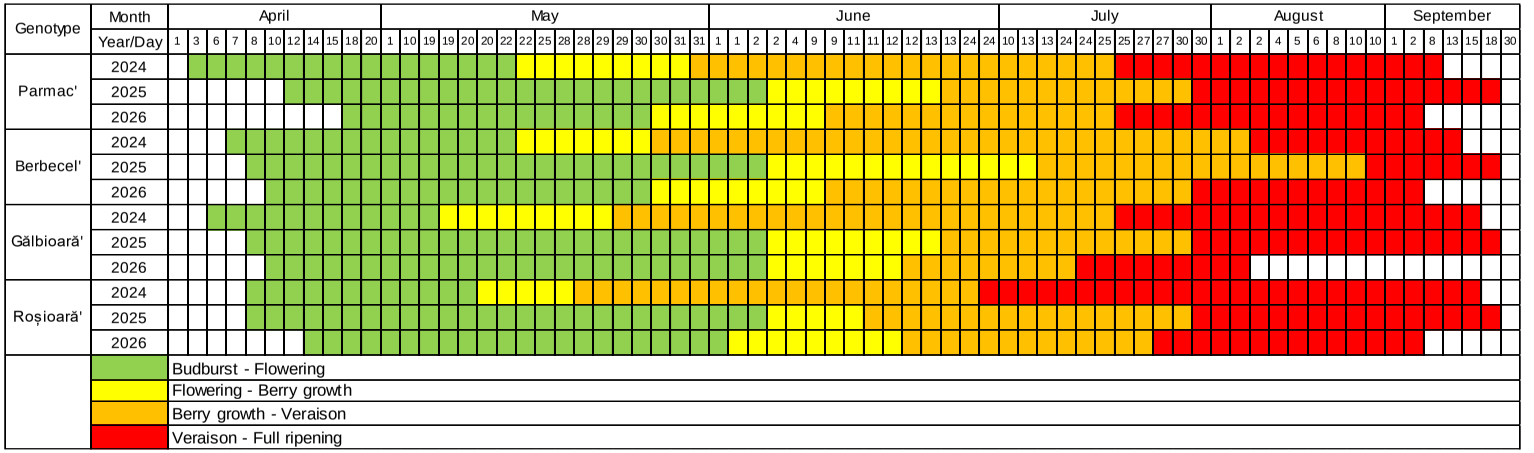


Figure 2. Phenogram of the period from budburst to full ripening for selected local grapevine genotypes, 2024–2026

Table 2.

Timing of the main phenological stages expressed as Day of Year (DOY) and duration of phenological intervals in the investigated grapevine genotypes during 2024–2026

Genotype	Year	Budburst (DOY)	Flowering (DOY)	Budburst–Flowering (days)	Veraison (DOY)	Flowering–Veraison (days)	Full ripening (DOY)	Veraison–Full ripening (days)	Budburst–Full ripening (days)
'Parmac'	2024	94	143	49	207	64	255	48	161
'Berbecel'		98	143	45	215	72	257	42	159
'Gălbioară'		97	140	43	207	67	260	53	163
'Roșioară'		99	141	42	206	65	248	42	149
'Parmac'	2025	100	153	53	211	58	261	50	161
'Berbecel'		98	153	55	222	69	261	39	163
'Gălbioară'		98	153	55	211	58	261	50	163
'Roșioară'		98	153	55	211	58	261	50	163
'Parmac'	2026	103	150	47	206	56	245	39	142
'Berbecel'		100	150	50	211	61	245	34	145
'Gălbioară'		100	153	53	205	52	245	40	145
'Roșioară'		104	152	48	208	56	250	42	146

Note: DOY, Day of Year; January 1 = DOY 1. The duration of each phenological interval was calculated as the difference between the DOY values of consecutive stages.

Temperature is one of the main factors determining the rate of progression through grapevine phenological stages, while the accumulation of temperatures above the biological activity threshold of 10 °C contributes to the successive occurrence of budburst, flowering, berry growth, veraison, and ripening (Parker et al., 2020).

The global heat balance recorded the highest value in 2024 (3927 °C), followed by 2025 (3709 °C) and 2026 (3566 °C). The same decreasing trend was observed for the active heat balance, with values of 3898 °C, 3683 °C, and 3482 °C, respectively, as well as for the useful heat balance, with values of 2098 °C, 1939 °C, and 1752 °C, respectively.

The downward trend observed in all three components indicates a progressive reduction in the thermal resources available during the analyzed period. The most pronounced difference between 2024 and 2026 was recorded for the useful heat balance, which decreased by 346 °C.

During the analyzed period, annual precipitation ranged from 357.8 mm in 2025 to 685.4 mm in 2026. Precipitation during the growing season reached its maximum in 2024, at 247.8 mm, while the minimum was recorded in 2025, at 141.0 mm. The number of days with precipitation was 114 in 2025 and 139 in 2026, with most rainy days concentrated during the cold season, which reduced water availability in the soil during the critical developmental stages of grapevine. In the absence of additional water supply, thermal and water stress became evident from June to August, a period characterized by very low precipitation and high temperatures, while the beginning of the growing season remained exposed to the risk of late frost, with sub-zero temperatures occurring as late as April.

The number of days with temperatures above 30 °C reached its highest value in 2024 (99 days) and its lowest value in 2026 (72 days).

Interannual climatic variability was reflected in the timing and duration of the main phenological stages of the studied genotypes. Budburst occurred earlier in 2024 and later in 2026, this pattern being associated with differences in thermal conditions at the beginning of the growing season (Figure 2).

During 2024–2026, budding occurred between DOY 94 and 104, flowering between DOY 140 and 153, maturity between DOY 205 and 222, and full maturity between DOY 245 and 261. The duration from budding to full maturity varied between 142 and 163 days, highlighting both interannual variations and differences between genotypes (Table 2.).

Budburst marks the onset of the cultivar specific developmental activity, which is nonetheless influenced by environmental factors—specifically, particular thermal conditions. In temperate climates, budburst in *Vitis vinifera* cultivars generally occurs during the first half of April, once an accumulated effective temperature of approximately 120–160°C has been reached and the average air temperature remains above 10°C for a period of 7–10 days (Irimia, 2012).

In 2024, budding occurred at DOY 94–99, and flowering at DOY 140–143. The ˈGălbioarăˈ genotype flowered the earliest (DOY 140), while the ˈParmacˈ and ˈBerbecelˈ genotypes reached this stage at DOY 143. The entry into maturity occurred at DOY 206–215, with the ˈRoșioarăˈ genotype being the earliest and the ˈBerbecelˈ genotype the latest. Full maturity was reached at DOY 248–260. The vegetation period, from bud break to full maturity, varied between 149 days for the ˈRoșioarăˈ genotype and 163 days for the ˈGălbioarăˈ genotype.

Following studies conducted in Alsace (Colmar), Duchêne and Schneider (2005) found that the period between budburst and harvest advanced and became shorter, while grape ripening occurred under higher temperature conditions.

In 2025, flowering was synchronized in all genotypes, at DOY 153. First fruiting was reached at DOY 211 in the ˈParmacˈ, ˈGălbioarăˈ and ˈRoșioarăˈ genotypes, while the Berbecel genotype reached this stage at DOY 222. Full maturity was synchronized at DOY 261, the vegetation period, from budding to full maturity, varied between 161 and 163 days.

In 2026, budding occurred at DOY 100–104, and flowering at DOY 150–153. The ˈParmacˈ and ˈBerbecelˈ genotypes flowered at DOY 150, and ˈGălbioarăˈ at DOY 153. Ripening occurred at DOY 205–211, and full maturity at DOY 245–250. The vegetation period, from bud break to full maturity, ranged between 142–146 days.

The most consistent genotypic peculiarity was observed in ˈBerbecelˈ, which presented the latest ripening in all three years. The difference was maximum in 2025, when the ˈBerbecelˈ genotype reached maturity at DOY 222, compared to DOY 211 for the other genotypes. Overall, 2026 was characterized by a shorter duration of the cycle from budding to full maturity, despite a later budding than in 2024. These differences suggest an important influence of thermal conditions on the duration of phenological stages.

Table 3.

Thermal characterization of the period from budburst to berry growth based on the sum of useful and active temperatures, 2024–2026

Genotype	Year	Budburst-Flowering			Flowering -Berry growth		
		Date	Σt active	Σt useful	Date	Σt active	Σt useful
'Parmac'	2024	3.04-22.05	773.8	273.8	22-31.05	181.0	81.0
'Berbecel'		7.04-22.05	711.0	251.0	22-30.05	163.2	73.2
'Gălbioară'		6.04-19.05	672.5	232.5	19-29.05	200.0	90.0
'Roșioară'		8.04-20.05	746.5	266.5	20.05-3.06	286.8	136.8
'Parmac'	2025	10.04-2.06	819.6	299.6	2.06-13.06	286.3	166.3
'Berbecel'		8.04-2.06	819.6	299.6	2.06-13.06	286.3	166.3
'Gălbioară'		8.04-2.06	819.6	299.6	2.06-13.06	286.3	166.3
'Roșioară'		8.04-2.06	819.6	299.6	2.06-11.06	241.8	141.8
'Parmac'	2026	13.04-30.05	715.2	275.2	30.05-9.06	238.5	128.5
'Berbecel'		10.04-30.05	715.2	275.2	30.05-9.06	238.5	128.5
'Gălbioară'		10.04-2.06	799.5	319.5	2.06-12.06	244.1	134.1
'Roșioară'		14.04-1.06	747.2	297.2	1.06-12.06	244.1	144.4

In 2024, during the period from budburst to flowering, the accumulated active temperature ranged from 672.5 °C in 'Gălbioară' genotype to 773.8 °C in 'Parmac' genotype. The accumulated effective temperature ranged from 232.5 °C to 273.8 °C. The most significant differences were observed between the onset of berry

growth and the onset of veraison. The 'Berbecel' genotype accumulated 1658.1 °C of active temperature and 1008.1 °C of useful temperature, values higher than those recorded for the other genotypes (Table 4).

During the period from veraison to harvest, the 'Gălbioară' genotype required 1306.8 °C of active temperature, whereas the 'Berbecel' genotype accumulated 1068.4 °C of active temperature during this period (Table 4).

In 2025, during the period from budburst to flowering, the accumulated temperature values were similar for all genotypes, reaching approximately 819.6 °C of active temperature and 299.6 °C of useful temperature. This uniformity is consistent with the onset of flowering occurring on the same date for all genotypes (Table 3).

During the period between berry growth and the onset of veraison, the 'Berbecel' genotype accumulated 1499.5 °C of active temperature and 909.5 °C of useful temperature, compared with 1220.8 °C of active temperature and 740.8 °C of useful temperature accumulated by 'Parmac' and 'Gălbioară'.

The higher values recorded for 'Berbecel' are associated with the longer duration of the period until the onset of veraison. This result is similar to that obtained in 2024 and supports the later phenological behavior of this genotype. The 'Roșioară' genotype showed intermediate values, namely 1267.2 °C of active temperature and 767.2 °C of useful temperature (Table 4).

Table 4.

Thermal characterization of the period from berry growth to full ripening based on the sum of useful and active temperatures, 2024–2026

Genotype	Year	Berry growth - Veraison			Veraison -Full ripening		
		Date	Σt active	Σt useful	Date	Σt active	Σt useful
'Parmac'	2024	31.05-25.07	1442.3	882.3	25.07-11.09	1225.2	735.2
'Berbecel'		30.05-2.08	1658.1	1008.1	2.08-13.09	1068.4	638.4
'Gălbioară'		29.05-25.07	1476.3	896.3	25.07-16.09	1306.8	766.8
'Roșioară'		3.06-24.07	1352.9	832.9	24.07-4.09	1096.4	666.4
'Parmac'	2025	13.06-30.07	1220.8	740.8	30.07-18.09	1184.5	674.5
'Berbecel'		13.06-10.08	1499.5	909.5	10.08-18.09	908.4	508.4
'Gălbioară'		13.06-30.07	1220.8	740.8	30.07-18.09	1184.5	674.5
'Roșioară'		11.06-30.07	1267.2	767.2	30.07-18.09	1184.5	674.5
'Parmac'	2026	9.06-25.07	1008.6	588.6	25.07-2.09	938.1	538.1
'Berbecel'		9.06-30.07	1240.7	720.7	30.07-2.09	819.5	469.5
'Gălbioară'		12.06-24.07	1026.1	596.1	24.07-2.09	957.2	547.2
'Roșioară'		12.06-27.07	1094.8	634.8	27.07-7.09	1038.0	588.0

In 2026, the sum of active temperatures between budburst and flowering ranged from 715.2 °C ('Parmac' and 'Berbecel') to 799.5 °C ('Gălbioară'), while the useful temperature ranged from 275.2 °C to 319.5 °C (Table 3).

During the period from berry growth to the onset of veraison, the 'Berbecel' genotype accumulated the highest value of active temperature, namely 1240.7 °C, and 720.7 °C of useful temperature. The 'Parmac' genotype accumulated 1008.6 °C of active temperature and 588.6 °C of useful temperature, while 'Gălbioară' and 'Roșioară' genotypes showed intermediate values.

During the period from veraison to full ripening, the 'Roșioară' genotype recorded 1038.0 °C of active temperature and 588.0 °C of effective temperature, whereas the 'Berbecel' genotype recorded 819.5 °C of active temperature and 469.5 °C of useful temperature (Table 4).

The thermal requirement for completing the entire growing cycle varies according to the cultivar maturity group. Thus, early-maturing cultivars require an accumulated active temperature of approximately 2500 °C, mid-maturing cultivars approximately 2900 °C, and late-maturing cultivars may require as much as 3300–3500 °C (Oprean, 1975; Popa, 2019).

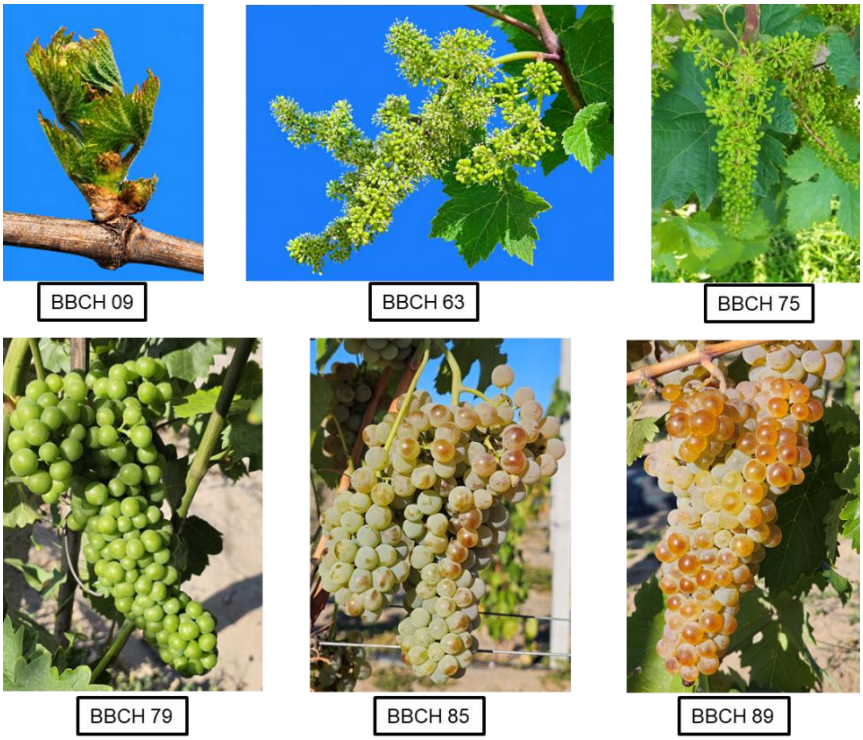


Figure 3. Main phenological developmental stages of grapevine according to the BBCH scale (original photographs).

CONCLUSIONS

The climatic conditions recorded during the 2024–2026 period at the Dăbuleni Research and Development Station for Plant Cultivation on Sandy Soils, were characterized by high thermal resources and relatively low precipitation, particularly during the growing season. Absolute maximum temperatures exceeded 39 °C in each experimental year, while 2025 was characterized by the lowest amount of precipitation during the April–September period.

The expression of phenological stages as DOY demonstrated clear interannual variation. Budburst occurred between DOY 94 and 104, flowering between DOY 140 and 153, veraison between DOY 205 and 222, and full ripening between DOY 245 and 261.

The duration of the complete phenological period from budburst to full ripening ranged from 142 to 163 days. The shortest periods were recorded in 2026, when the investigated genotypes completed the cycle 3–21 days earlier than in 2024 and 16–21 days earlier than in 2025, depending on genotype.

Interannual climatic variability influenced the timing of the main phenological stages. Budburst occurred earlier in 2024 and later in 2026, this pattern being associated with differences in thermal conditions at the beginning of the growing season.

Phenological differences among genotypes were relatively small during the period from budburst to flowering and became more pronounced between berry development and the onset of veraison.

The 'Berbecel' genotype consistently exhibited the latest phenological behavior. In each of the three experimental years, this genotype reached the onset of veraison later than the other genotypes and accumulated the highest sums of active and effective temperatures during the period from berry growth to the onset of veraison.

The 'Parmac', 'Gălbioară', and 'Roșioară' genotypes generally entered the veraison stage earlier; however, their phenological sequence varied among years, highlighting the interaction between genetic characteristics and annual climatic conditions.

The results demonstrate the importance of evaluating and conserving local grapevine genotypes, as phenological diversity and differences in responses to thermal resources may represent important characteristics for adapting viticulture to future climatic conditions.

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