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SUITABILITY OF SOME *V. VINIFERA* VARIETIES AND CLONES IN THE CURRENT CLIMATIC CONTEXT OF SOUTHWESTERN ROMANIA

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Abstract

The selection and promotion of valuable grapevine clones and varieties in vineyards can be a way in the strategy for adaptation and resilience to climate change, but also a possibility to offer consumers with a diverse range of wines characterized by complexity and typicity. The aim of this study was to evaluate the adaptation potential of some grapevine varieties and clones in the context of seasonal climate variability in South-West Romania. Seven V. vinifera varieties and clones were studied: 'Chardonnay' clones R8, VCR4 and 95, 'Tămâioasă românească', 'Fetească neagră', 'Merlot'; and 'Cabernet Sauvignon' clone ISV 117, grafted on V. Berlandieri x V. Riparia SO4 rootstock. Aspects regarding phenological stages, bioproductive parameters (bud fertility, grape yield, grape weight) and qualitative parameters (soluble sugars, total acidity) were evaluated. Rising temperatures and water scarcity are constant challenges in the wine-growing areas of southwestern Romania. The effects of warming and drying from flowering to full ripening generated a decrease in production by 38.56%, production losses ranging from 25.41% ('Chardonnay' clone 95) to 44.59% in Merlot.

Key words*: climatic change, grapevine, phenological stages, high temperatures, bud fertility.*

INTRODUCTION

The viticulture and winemaking sector plays an important role in Romania's agriculture and economy.

Climatic resources, along with other terroir factors, play a primary role in the growth and development of grapevine, influencing metabolism and physiological processes, with implications for the production and quality of grapes and, implicitly,the quality of wines (Costea et al., 2023).

Medium- and long-term climate scenarios show important variations in atmospheric patterns (Rességuier et al., 2020; Schultz, 2016), which can affect viticultural geography (Jones et al., 2005) grapevine phenology, grape production, and wine quality (Muñoz et al., 2021; Neethling et al., 2019). Modeling the effects of increased temperatures, according to different scenarios, on the evolution of climate change at the geoviticultural level is an important concern and provides useful information on the choice of suitable varieties for vineyards (Duchêne et al., 2010; Zapata et al., 2017), establishing the optimal harvest time according to the desired sugar content for a certain type of wine (Molitor et al., 2020).

The climate change noticed in recent decades generates significant challenges for the vine and wine sector at the global and European levels (Cardell et al., 2019; Santos et al., 2020). Vineyards in Eastern Europe are experiencing increased water stress amid rising temperatures, erratic rainfall, and prolonged periods of drought (Filimon et al., 2024; Florea et al., 2025). In recent decades, in all wine-growing regions in Romania, there has been a significant increase in the average annual temperature (Iliescu et al., 2019) and in the frequency and intensity of heat waves (Bucur & Babeș, 2016; Croitoru et al., 2016), as well as a reduction in the frequency of freezing periods (Cichi et al., 2021).

The production and quality of the viticultural raw material and, implicitly, of the wine are directly influenced by climatic conditions (Van Leeuwen et al., 2019). The consequences of climate warming in the veraison-ripening interval on the quality of grapes at harvest must be taken into account in future grapevine breeding programs (De Cortazar Atauri et al., 2017) or cultivation practices (Bucur et al., 2024).

The stress caused by water scarcity can have the effects of limiting photosynthesis, slowing down the growth of shoots, and reducing the size of the berries, but also stimulating the synthesis of some phenolic compounds (van Leeuwen et al., 2008) and some volatile organic compounds (Savoi et al., 2016).

Recent studies focusing on wine-growing areas in the southwestern Romania region have shown that the changes and trends detected (1961-2021 period) for a series of climate indices used in viticultural climatology may generate pressure to obtain quality wines from certain grape varieties, amid the increase in temperature and reduced amounts of rainfall during the growing season (Irimia et al., 2018; Mărăcineanu et al., 2021; Vlăduț et al., 2023).

At national and regional levels, there is ongoing interest from the scientific community, but also from operators in the viticulture and wine sector, in identifying solutions to counteract the negative effects of the challenges generated by climate change (Nistor et al., 2022).

The use of genetic variability in grapevines (varieties, clones, rootstocks) is a possibility intensely explored in research aimed at adapting to climate change (Cichi et al., 2022; Zaldea et al., 2021), along with the identification of new cultivation zones (Irimia et al., 2018; Licurici et al., 2025) or various training systems (Băducă et al., 2020; Gatti et al., 2016; Trought et al. 2015). The selection and promotion of valuable grapevine clones and varieties in vineyards can be a way in the strategy of adaptation and resilience to climate change, but also a possibility to offer consumers a diverse range of wines, characterized by complexity and typicity.

The aim of this study was to evaluate the adaptation potential of some traditional grapevine varieties and new grapevine clones introduced in the assortment, in the context of seasonal climate variability in southwestern Romania.

MATERIALS AND METHODS

Location and climatic characteristics. The study was conducted for the 2023 and 2024 vintages in a wine grape vineyard located at the Didactic Research Station of the University of Craiova (Dealurile Craiovei vineyard, *Hills of Muntenia and Oltenia winegrowing Region*), in south-western Romania. The vineyard area is located between the parallels of 44°29' north latitude and 23°87' east longitude (190 m elevation). Hills of Muntenia and Oltenia winegrowing ranks second in terms of winegrowing area at the national level, the Oltenia winegrowing sub-region being representative for the quality and diversity of its wines.

Climate characteristics. The climatic data were obtained from the following source: Klein Tank et al, 2002 (data and metadata available at http://www.ecad.eu for the Craiova meteorological station- 44°13' latitude and 23°52' longitude, 192 m altitude, Dolj County). Climate suitability was assessed by bioclimatic indices such as: average annual temperature, sum of average daily temperature > 10°C, April 1st to September 30th (SAT), the growing season average temperature (April 1st to September 30th), the Huglin Index -IH), the annual and growing season rainfall (mm), the Winkler Index (Winkler et al., 1974), the number of days with maximum temperatures >30 °C (April 1st to September 30th), the De Martonne Aridity Index, and the Nights Cold Index -CI (Tonietto & Carbonneau, 2004).

Plant material. Seven *V.vinifera* varieties and clones were studied: 'Chardonnay' clones 95, R8 and VCR4, 'Tămâioasă românească', 'Fetească neagră', 'Merlot'; and 'Cabernet Sauvignon' clone ISV 117, grafted onto *V. Berlandieri x V. Riparia* SO4 rootstock. The study was conducted on 9 year-old vines. The vines were cultivated under the same growing conditions, on reddish-brown soil, with the 2.2 x 1.2 m spacing, a semi-tall shape of the stem (with a trunk of 0.8 m), Cordon spur pruning: 32 buds/vine, without irrigation. The viticultural management was applied for all varieties and clones in the same way. The randomized experimental design was used. Five vines per variety/clone were selected for the study in three replications.

Phenology data. Budburst (BBCH 07), flowering (BBCH 65), veraison (BBCH 81) and

fully ripening (BBCH 89) were considered (Lorenz et al., 1995). The Day of the Year (DOY) and the cumulated Growing Degree Day (GDD) since DOY to reach the main phenological stages were determined.

Agrobiological, quantitative, and qualitative characteristics. The absolute and relative fertility index (Afi and Rfi) were established and calculated according to Cichi et al., 2022.

Sampling measurement, and analyses. The measurements and analyses of yield and quality of the production were conducted at harvest. The average yield (kg/vine), the average weight of grapes (in g) were analysed. Sugar content (g/L) was measured and determined using a Kruss Optronic Hand Refractometer Hrot 32. Titratable acidity (g/L H_2SO_4) was determined by the titration method using NaOH 0,1N until pH 7.0. Sugar content and titratable acidity measurements were performed in three replicates.

Statistical analysis. The analysis of variance (one-way ANOVA) was applied for each variable evaluated. All variables significant in the F test were analysed using Tukey`s HSD test for $p < 0.05$. The data are presented as mean ± standard deviation of each variable.

RESULTS AND DISCUSSIONS

Climatic characteristics. The main climatic characteristics during the study period are shown in Table 1. Compared with the multiannual average values (1961-2021), evident warming is observed during the study period. The average annual temperature was higher by 2.43° (2023) and 3.43° (2024).

The values of growing degree days from 1 April to 31 October (Winkler index) total 2000 to 2312 units, which places the investigated area and the study years in Winkler climate class IV (temperate, 2023) and V (warm, 2024), indicating a favorable climate for grape varieties suitable for producing high-quality wines (Winker et al., 1974).

Compared to the 2023 growing season, there was significant warming in the 2024 growing season, the number of days with maximum temperatures >30 °C being 92 days, of which 60 days occurred during July-August, during the veraison-fully ripening period. The increase in the number of days with maximum temperatures >30 °C before harvest has also been reported in other vineyards worldwide (Van Leeuwen et al., 2019; Vršič et al., 2024), with effects on the rate and timing of ripening and the quality of grapes and wines. The year 2024 was also marked by a significant deficit of precipitation, being suboptimal both in terms of annual rainfall and during the growing season. The De Martonne Aridity Index growing season clearly demonstrates the arid character of the climate in the 2024 growing season (Table 1).

Phenological characteristics. In the context of climate change, knowing the projection of phenological stages in grapevines will play an important role in the decisions that grapevine growers and wine producers will make (Piña-Rey et al., 2021).

The climate specificity of the harvest year had a significant effect, in terms of the time of reaching the main phenological stages, as well as the amount of GDD for budburst and full ripening (Table 2).

The variety had a significant influence through GDD in achieving veraison (Table 3).

Table 1. Main climatic indexes of the experimental site

Climatic Index	Average 1961-2021	2023 Year	2024 Year
Average annual temperature	11.2*	13.63	14.33
Growing average season temperature (April 1st to September 30th)	-	19.78	22.00
SAT (Sum of average daily temperature > 10°C, April 1st to September 30th)	-	3585	3988
Winkler Index (April 1st to October 31th)	1706*	2000	2312
Huglin`s heliothermal index (IH)	2261*	2484	2923
Number of days with maximum temperatures >30 °C (April 1st to September 30th)	-	46	92
Annual Rainfall (mm)	606.6**	575.4	357.3
Rainfall in the growing season (mm, April 1st to September 30th)	349.7*	318.2	175.2
De Martonne Aridity Index (I_{DM}, year)	-	24.35	14.69
De Martonne Aridity Index growing season (I_{DM}, April 1st to September 30th)	-	10.69	5.47
Nights Cold Index CI (°C)	12.1*	15.02	13.72

*Source: *Vlăduț et al., 2023 ; **calculated*

Table 2. Seasonal evolution (DOY) and cumulated Growing degree days (GDD) in grapevine at main phenological stages by vintage

Vintage year	Budburst (BBCH 08)		Flowering (BBCH 65)		Veraison (BBCH 81)		Fully Ripening (BBCH 89)	
	DOY	GDD	DOY	GDD	DOY	GDD	DOY	GDD
2023	114±4.26[a]	78.57±10.64[b]	162±8.29[a]	346.86±25.82	215.14±4.06[a]	1108±48.56	252 ±3.37[a]	1,622±43.34[b]
2024	104±2.34[b]	132.86±19.13[a]	145±4.90[b]	370.86±20.46	197.86±2.91[b]	1144±53.24	242±5.50[b]	1,977±93.76[a]
Significance	***	***	**	NS	NS	NS	**	**
Minimum date	10 –April		22- May		12- Jul.		24-Aug.	
Maximum date	3 -May		16- Jun.		11-Aug.		14-Sept.	

Note: *** = significant at P ≤ 0.001, ** = significant at P ≤ 0.01, * = significant at P ≤ 0.05, NS = non-significant.

Table 3. Cumulated growing degree days (GDD) and DOY at main phenological stages by varieties and clone (mean 2023-2024 vintage)

Variety/Clone	Budburst (BBCH 08)		Flowering (BBCH 65)		Veraison (BBCH 81)		Fully Ripening (BBCH 89)	
	DOY	GDD	DOY	GDD	DOY	GDD	DOY	GDD
Chardonnay clone 95	106	87	150	335	204	1,087[b]	243±8	1,749±218
Chardonnay clone R8	108	101	151	339	205	1,103[ab]	244±6	1,754±257
Chardonnay clone VCR4	108	101	152	344	205	1,107[ab]	244±7	1,752±239
Tămâioasă românească	109	108	154	364	204	1,076[b]	247±11	1,802±190
Fetească neagră	108	100	153	354	207	1,128[ab]	245±8	1,773±231
Merlot	111	114	156	385	209	1,169[ab]	250±8	1,844±283
Cabernet Sauvignon	116	132	157	394	213	1,215[a]	255±3	1,924±339
Mean	109±6 [NS]	106±32 [NS]	153±9 [NS]	359±26 [NS]	207±10 [NS]	1,126±52*	247±7 [NS]	1,800±197 [NS]

Note: *** = significant at P ≤ 0.001, ** = significant at P ≤ 0.01, * = significant at P ≤ 0.05, NS = Non-significant.

There were no significant differences between the three clones of 'Chardonnay' concerning the attainment of the phenological stages or GDD.

Budburst occurred earliest on 10 April (in 'Chardonnay' clone 95) and at the latest on 3 May (in 'Cabernet Sauvignon' ISV 117 clone). Budburst ranged from 87 GDD ('Chardonnay' clone 95) to 132 GDD ('Cabernet Sauvignon' ISV 117 clone). Flowering (BBCH 65) ranged from 335 GDD to 394 GDD, occurring from 22 May to 16 June. Early flowering is noticeable in the 'Chardonnay' clones and, among the varieties for red wines, in the 'Fetească neagră' variety. The veraison range was from 1076 GDD to 1215 GDD, with earliest occurring on 12 July 2024 and the latest on 11 August. There are statistically significant differences regarding the early veraison only for 'Chardonnay' clone 95 and 'Tămâioasă românească' compared to 'Cabernet Sauvignon' ISV 117 clone (Table 3).

In order to establish fully ripened fruit, the minimum level of 190 g/L of sugar was established for the clones of 'Chardonnay' and 'Tămâioasă românească' and the minimum level of 204 g/L for the red wine varieties, in accordance with the regulations in force provided in the *Banu Mărăcine DOC Wine Specifications* submitted in 2011 to the European Commission – according to Art. 118s, of Regulation (EC) 1234/2007.

Fully ripening ranged from 1749 GDD in the 'Chardonnay' clone 95 to 1924 GDD in the 'Cabernet Sauvignon' ISV 117 clone. The average duration of the veraison-fully ripening interval was 41 DOY in the two years of study, decreasing compared to previous years. Against the background of high average daily temperatures, a high number of maximum daily temperatures above 30°C (NDT 30) throughout the 2024 growing season (of which 56 DOY in the veraison-ripening interval) and a significant deficit of rainfall (Table 1), the full ripening of grapes had an advance (precocity) between 4-15 days compared to 2023. An exception, however, was the 'Cabernet Sauvignon' ISV 117 clone, which retains its late character in full grape ripening (Table 3).

Fertility and productivity. In terms of fertility, the 'Chardonnay' 95 clone in 2023 and the 'Cabernet Sauvignon' ISV 117 clone in 2024 were noted by a higher number of inflorescences reported to the total number of shoots per vine (R.f.i). Regarding the number of inflorescences on fertile shoots (A.f.i), significant differences between genotypes were highlighted only in 2024, showing the the 'Cabernet Sauvignon' ISV

117 clones showing an average of 1.50 inflorescences/fertile shoot (Table 4).
In relation to the interannual variability of fertility, significant differences were observed in the variety 'Tămâioasă românească' for R.f.i, respectively in the the 'Chardonnay' R8 and VCR4 clones and the the the 'Cabernet Sauvignon' ISV 117 clone for A.f.i. In vintage 2024, with the exception of the 'Cabernet Sauvignon' ISV 117 clone, all genotypes showed a lower number of inflorescences on the fertile shoots (A.f.i), Table 4.

Table 4. Fertility and productivity characteristics in varieties and clones*

Variety/Clone	Vintage	R.f.i	A.f.i	Bunch weight (g)	Yield (Kg/vine)	± % Yield Vintage 2024/2023
Chardonnay clone 95	2023	0.78 ±0.14^{abA}	1.24 ±0.07^{aA}	166.86 ±14.03^{cA}	1.43 ±0.24^{cdA}	*- 25,41%*
	2024	0.82 ±0.06^{bcA}	1.17 ±0.09^{bcA}	134.62 ±9.71^{bcB}	1.07±0.16^{bA}	
Chardonnay clone R8	2023	0.70 ±0.12^{abA}	1.25 ±0.07^{aA}	161.04 ±15.60^{cdA}	1.98±0.19^{bcA}	*- 33,05%*
	2024	0.71 ±0.06^{cA}	1.01 ±0.07^{cB}	110.33 ±18.88^{bcB}	1.33±0.13^{abB}	
Chardonnay clone VCR4	2023	1.06 ±0.19^{aA}	1.42 ±0.09^{aA}	191.63 ±17.56^{bcA}	2.25 ±0.48^{bcA}	*-43,11%*
	2024	0.83 ±0.07^{bcA}	1.13 ±0.04^{bcB}	150.97 ±19.20^{bcA}	1.28±0.08^{abB}	
Tămâioasă românească	2023	0.65 ±0.07^{bB}	1.40 ±0.20^{aA}	250.13 ±39.68^{abA}	2.58 ±0.33^{bA}	*-36,60%*
	2024	0.88 ±0.04^{bcA}	1.27 ±0.06^{bA}	184.07 ±14.19^{aA}	1.64 ±0.18^{aB}	
Fetească neagră	2023	0.76 ±0.08^{abA}	1.23 ±0.07^{aA}	261.35 ±33.09^{aA}	2.16 ±0.33^{bcA}	*-43,12%*
	2024	0.78 ±0.07^{bcA}	1.11 ±0.07^{bcA}	159.38 ±15.54^{abB}	1.23 ±0.10^{abB}	
Merlot	2023	0.96 ±0.15^{abA}	1.40 ±0.11^{aA}	164.07 ±18.03^{cA}	3.11 ±0.28^{abA}	*-44,59%*
	2024	0.90 ±0.04^{bA}	1.26 ±0.03^{bA}	125.34 ±15.83^{bcB}	1.72 ±0.32^{aB}	
Cabernet Sauvignon ISV 117	2023	0.89 ±0.10^{abA}	1.14 ±0.10^{aB}	143.03 ±16.11^{cdA}	2.12 ±0.30^{bcA}	*-38,30%*
	2024	1.06 ±0.06^{aA}	1.50 ±0.08^{aA}	101.17 ±16.52^{cB}	1.31 ±0.26^{abB}	
Mean 2023		0.85±0.20^{A}	1.32 ±0.14^{A}	191.17 ±48.49^{A}	2.23±0.33^{A}	*-38.56%*
Mean 2024		0.85±0.12^{A}	1.21 ±0.16^{B}	137.98 ±30.57^{B}	1.37±0.07^{B}	

*Note: Means ± S.D.; Means separation by HSD Tukey`s test at p≤ 0.05; Means with the same superscript are not statistically significant. In the column: the small letters indicate the significance of the differences between the varieties and clones for the same variable and vintage; capital letters represent the significance of the differences between the vintages

Table 5. Main qualitative characteristics in grapevine varieties and clones at harvest*

Variety/Clone	Vintage	Sugar content (g/L)	Titrable acidity (g/L H_2SO_4)
Chardonnay clone 95	2023	209.93±3.05^{bcB}	4.26±0.07^{abA}
	2024	218.20±3.55^{bcA}	3.85±0.08^{cB}
Chardonnay clone R8	2023	204.73±6.00^{cA}	4.25±0.10^{abA}
	2024	214.94±4.51^{cA}	3.96±0.09^{bcB}
Chardonnay clone VCR4	2023	208.34±5.92^{bcA}	4.14±0.06^{bA}
	2024	218.87±2.96^{bcA}	3.82±0.15^{cB}
Tămâioasă românească	2023	218.23±2.25^{bB}	4.46±0.06^{aA}
	2024	224.80±2.92^{bA}	4.15±0.07^{abB}
Fetească neagră	2023	224.60±2.85^{abB}	4.43±0.09^{aA}
	2024	236.87±2.30^{aA}	4.24±0.04^{aB}
Merlot	2023	227.07±2.38^{abB}	4.20±0.13^{bA}
	2024	234.67±2.61^{aA}	4.24±0.05^{aA}
Cabernet Sauvignon ISV 117	2023	231.03±4.25^{aA}	4.42±0.09^{aA}
	2024	236.00±2.72^{aA}	4.21±0.10^{aB}
Mean 2023 vintage		217.70±10.28^{B}	4.31±0.14^{A}
Mean 2024 vintage		226.33±9.19^{A}	4.07±0.19^{B}

*Note: Means ± S.D.; Means separation by HSD Tukey`s test at p≤ 0.05; Means with the same superscript are not statistically significant. In the column: the small letters indicate the significance of the differences between the varieties and clones for the same variable and vintage; capital letters represent the significance of the differences between the vintages.

Significantly greater differences in the average weight of the grape in vintage 2023 were recorded for the 'Fetească neagră' variety (261.35 g). With the exception of the clone 'Chardonnay' VCR 4 and the 'Tămâioasă românească' variety, the average weight of grapes in 2024 was significantly reduced compared to 2023, ranging between 101.17 g ('Cabernet Sauvignon' ISV 117) and 184. 07 g ('Tămâioasă românească'). Production was

decreased by an average of 38.56% in vintage 2024 compared to vintage 2023, with production losses ranging from 25.41% (‘Chardonnay’ clone 95) to 44.59% in 'Merlot'. There were no statistically significant differences between the three ‘Chardonnay’ clones in terms of grape weight and yield/vine.

Quality characteristics. Knowing the ripening time and the time needed to reach the sugar concentrations in the traditional vine varieties for the wine region ((Fraga et al., 2014), depending on the temperature dynamics in the growing season or veraison-ripening and the desired style of wine, are very important for obtaining balanced wines, with variety typicity and specificity for the viticultural terroir.

The climatic conditions of the vintages and the genetic potential of the grape varieties significantly influenced the levels of the main chemical constituents of the grapes (Table 5). Under heat stress and water deficit conditions in the 2024 season, all varieties recorded higher sugar content and lower acidity at harvest, although the ripening phenophase occurred 4-15 days earlier compared to vintage 2023. The clones 'Chardonnay' VCR 4 and 95 and 'Cabernet Sauvignon' ISV 117 did not experience significant sugar increases between the two vintages. The dehydration of berries explains, to a certain extent, the increase in sugar concentrations at harvest, which was evident in 2024, under conditions of high temperatures in the veraison-fully ripening interval and water deficit. From the point of view of acidity, it is found that the varieties for red wines, under the same restrictive climate conditions, registered a fairly good content compared to some varieties/clones for white wines in which the acidity decreased significantly.

Interestingly, the Merlot variety, although not known as a drought-tolerant variety, did not register significant differences in acidity under conditions of water scarcity in the 2024 growing season; however, the production losses recorded were significant.

CONCLUSIONS

Rising temperatures and water scarcity are constant challenges in the wine-growing areas of southwestern Romania. The effect of warming and drying during flowering-fully ripening generated a decrease in production of 38.56 %, production losses were between 25.41 % (‘Chardonnay’ clone 95) and 44.59 % in Merlot. Complex approaches are needed regarding the specific response reactions of grapevine varieties (traditional/recently introduced in the assortment) in the current climatic context and agro-management practices in order to better understand the genotype-terroir interaction, to have a predictable picture of the evolution,, and an adequate response for the viticulture and winemaking sector in the context of the prefigured climate scenarios in the medium and long term. The development and implementation of adequate strategies for adaptation to climate change in the wine-growing areas of the southwestern region of Romania are a pressing necessity to ensure sustainable viticulture, the preservation of the typicality of the wines, and the specificity of the terroirs of this region.

The overall analysis of the results highlights, in the current context, the necessary conditions for obtaining high-quality red wines from the Cabernet Sauvignon, Merlot, and Feteasc ă neagră varieties, provided that the evolution of grape ripening is rigorously monitored every year and the selection of the most appropriate harvesting times is done when the ratios between sugars and acidity are fully in line with the type of wine to be produced.

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