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SUPPLEMENTARY MATERIAL

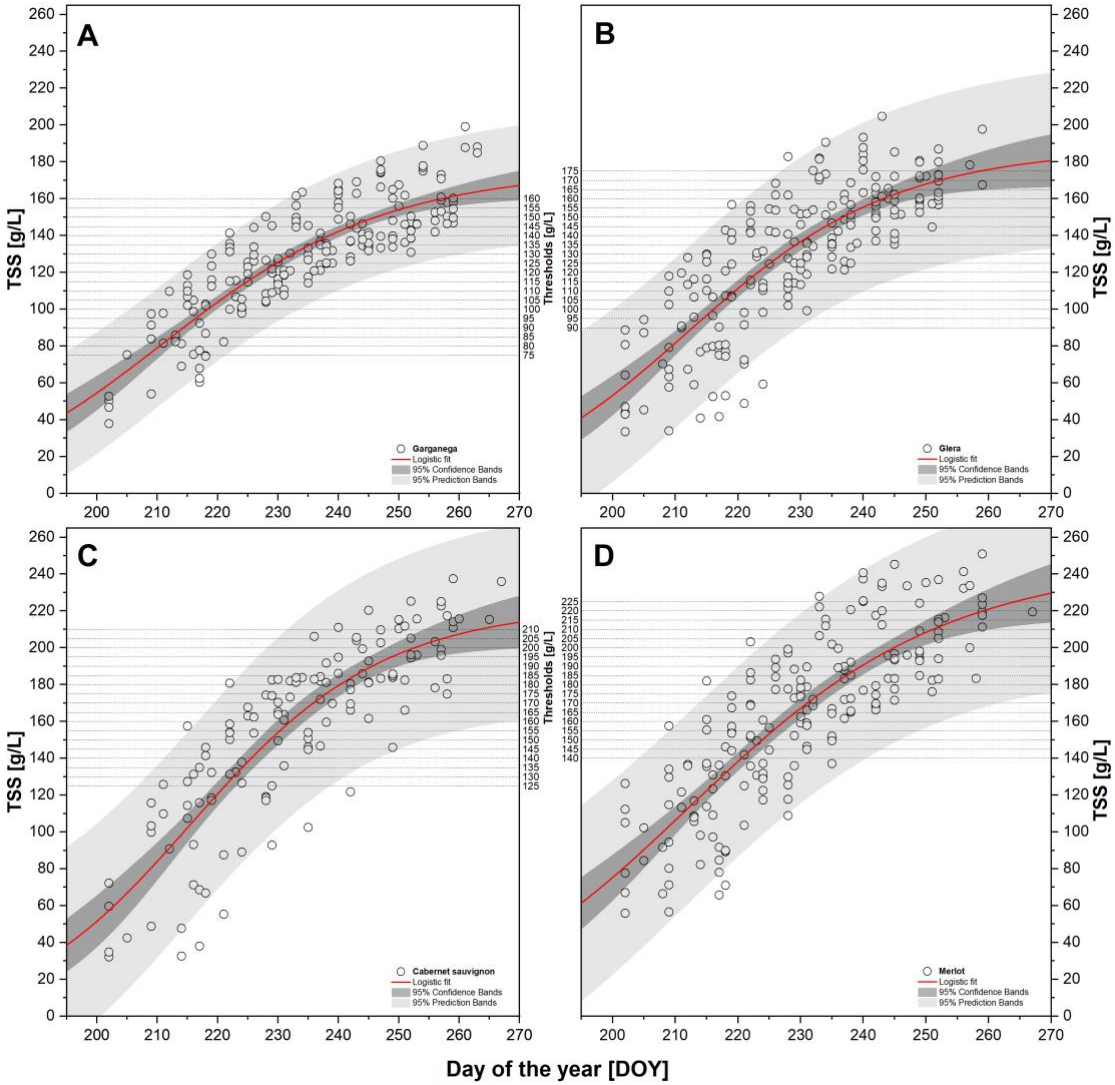


FIGURE 1SM. Mean increments of berry total soluble solids (TSS) (g/L) on a day-of-the-year (DOY) basis in the Lonigo area (NorthEast Italy) over a 13 year period (2009 to 2021) for Garganega (GA), Glera (GL), Cabernet Sauvignon (CS) and Merlot (ME).

Red solid lines represent best fit logistic function for mean ripening dynamics over the baseline period (2009-2021) and light to dark grey areas represent the 95% prediction and 95% confidence intervals limits, respectively. For each variety, horizontal dotted lines represent 18 specific thresholds at which ripening anomalies either advances or delays in DOY to specified target ripeness thresholds were assessed with respect to the average ripening dynamics (solid red line). Fitting parameters resulting by non-linear regression and relative goodness-of-fit metrics are reported in **Table 1SM**.

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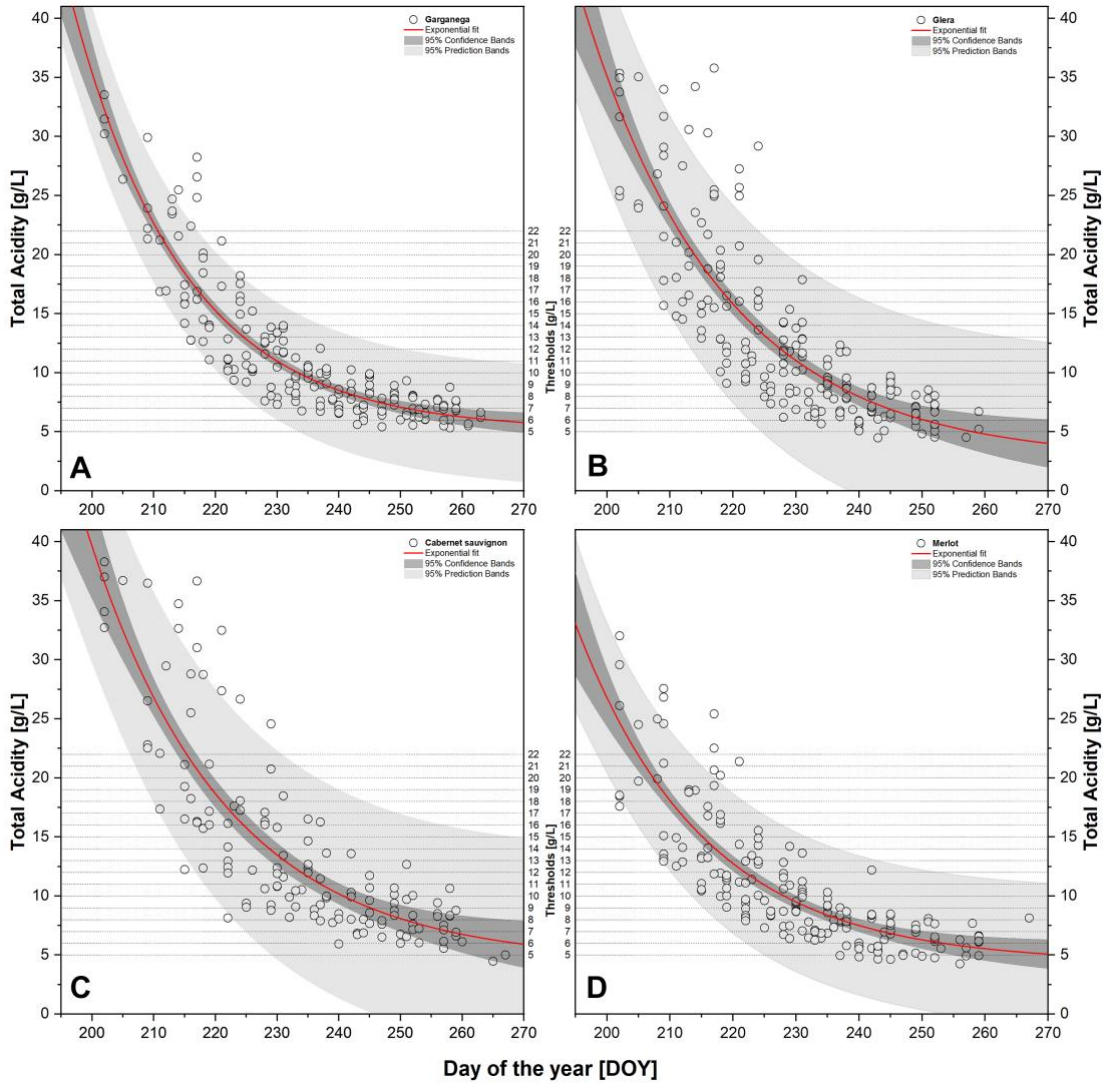


FIGURE 2SM. Mean berry total acidity (TA) levels decrement (g/L) on a day-of-the-year (DOY) basis in the Lonigo area (NorthEast Italy) over a 13-year period (2009 to 2021) for Garganega (GA), Glera (GL), Cabernet Sauvignon (CS) and Merlot (ME).

Red solid lines represent best fit exponential decay function for mean ripening dynamics over the baseline period (2009-2021) and light to dark grey areas represent the 95% prediction and 95% confidence intervals limits, respectively. For each variety, horizontal dotted lines represent 18 specific thresholds at which ripening anomalies either advances or delays in DOY to specified target ripeness thresholds were assessed with respect to the average ripening dynamics (solid red line). Fitting parameters resulting by non-linear regression and relative goodness-of-fit metrics are reported in **Table 2SM**.

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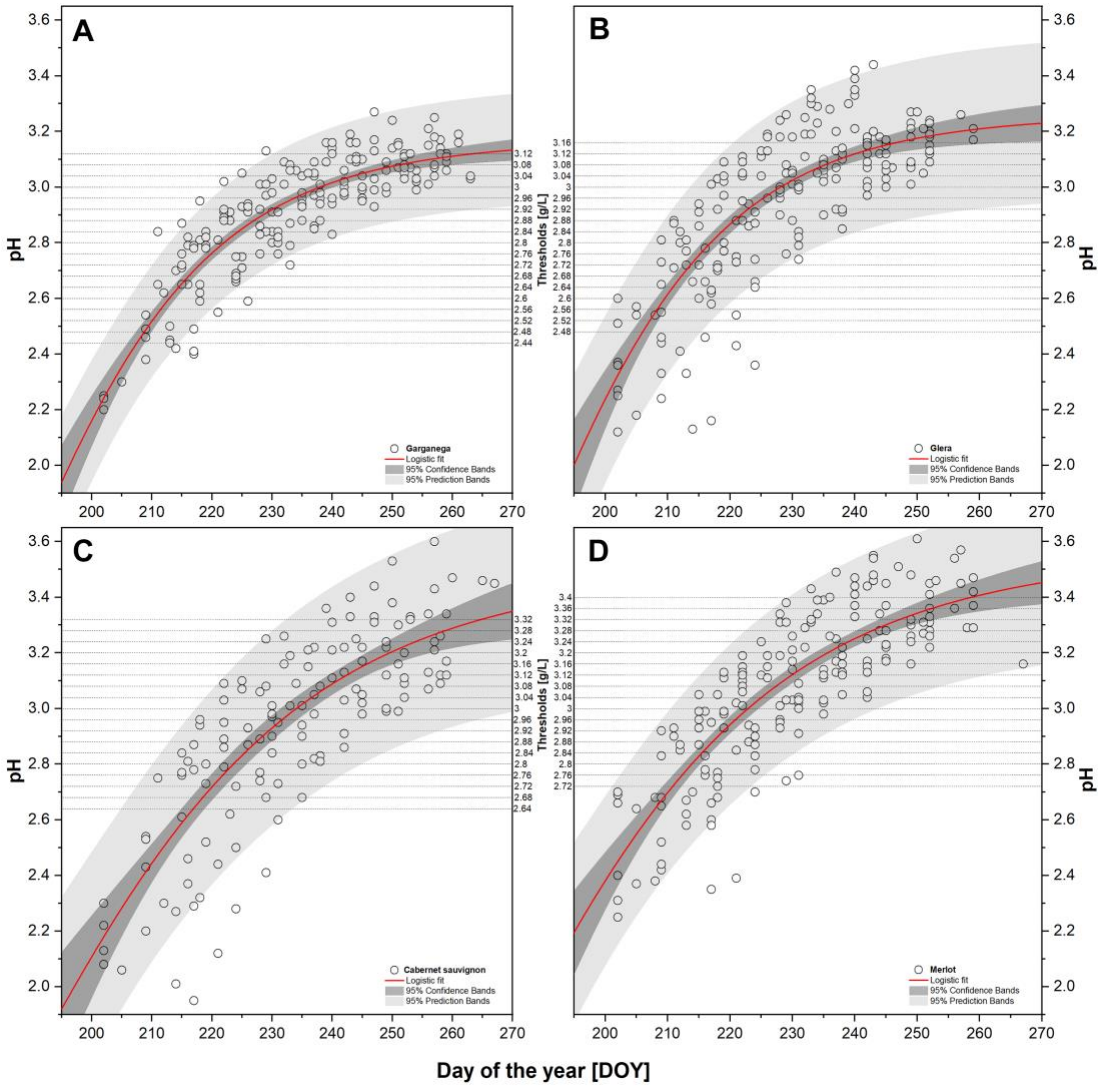


FIGURE 3SM. Mean increments of berry juice pH on a day-of-the-year (DOY) basis in the Lonigo area (NorthEast Italy) over a 13-year period (2009 to 2021) for Garganega (GA), Glera (GL), Cabernet Sauvignon (CS) and Merlot (ME).

Red solid lines represent best fit logistic function for mean ripening dynamics over the baseline period (2009-2021) and light to dark grey areas represent the 95% prediction and 95% confidence intervals limits, respectively. For each variety, horizontal dotted lines represent 18 specific thresholds at which ripening anomalies either advances or delays in DOY to specified target ripeness thresholds were assessed with respect to the average ripening dynamics (solid red line). Fitting parameters resulting by non-linear regression and relative goodness-of-fit metrics are reported in **Table 3SM**.

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TABLE 1SM. Fit parameters and goodness of fit metrics for the three-parameter logistic functions used to model berry TSS increments during the season on a day-of-the-year (DOY) basis (Eq. 1).

Variety	Year	R^2	RMSE (g/L)	RRMSE (%)	EF	a (g/L)	b	X_0 (DOY)
Garganega (GA)	*2009/2021*	*0.73*	*15.82*	*12.28%*	*0.73*	*176.96*	*-12.13*	*213.72*
	2009	0.95	5.84	4.79%	0.97	258.54	-7.43	238.17
	2010	0.94	7.39	5.60%	0.95	173.93	-18.11	220.38
	2011	0.97	5.05	5.21%	0.99	150.05	-29.61	206.56
	2012	0.95	6.27	4.85%	0.96	161.59	-28.37	212.18
	2013	0.96	5.56	4.61%	0.98	153.56	-21.60	219.46
	2014	1.00	2.63	2.57%	1.00	149.89	-16.86	215.73
	2015	0.81	9.36	6.67%	0.81	188.65	-9.00	207.56
	2016	0.95	5.66	4.95%	0.98	178.16	-10.75	221.11
	2017	0.99	3.18	2.28%	0.99	184.92	-17.63	208.64
	2018	0.94	4.68	3.87%	0.97	160.77	-10.20	205.93
	2019	0.61	15.84	10.72%	0.62	178.63	-16.51	218.36
	2020	0.69	14.73	10.19%	0.69	241.59	-6.70	225.34
	2021	0.78	5.48	4.23%	0.78	143.38	-33.96	219.39
Glera (GL)	*2009/2021*	*0.64*	*22.93*	*17.73%*	*0.64*	*188.34*	*-13.62*	*214.15*
	2009	0.95	4.25	3.59%	0.98	150.20	-24.84	212.94
	2010	0.96	7.04	5.47%	0.96	186.23	-19.94	223.24
	2011	0.85	12.45	11.19%	0.92	190.26	-19.35	207.76
	2012	0.87	12.72	8.58%	0.88	197.82	-24.23	213.77
	2013	0.85	13.99	11.17%	0.88	174.21	-20.72	221.34
	2014	0.94	10.00	10.21%	0.97	172.68	-14.50	221.30
	2015	0.93	11.04	8.73%	0.94	176.25	-20.21	212.48
	2016	0.91	10.15	8.91%	0.95	162.77	-20.46	219.76
	2017	0.78	20.97	15.45%	0.79	202.41	-17.43	211.31
	2018	0.67	14.93	11.02%	0.70	168.90	-19.48	206.99
	2019	0.73	13.97	9.14%	0.77	191.49	-17.05	219.14
	2020	0.99	4.40	3.28%	0.99	172.57	-25.60	213.61
	2021	0.90	11.61	8.71%	0.90	172.11	-32.76	223.46
Cabernet Sauv. (CS)	*2009/2021*	*0.72*	*25.59*	*16.41%*	*0.72*	*223.62*	*-14.32*	*217.58*
	2009	0.89	10.36	6.14%	0.94	222.96	-18.27	214.25
	2010	0.99	4.95	3.08%	0.99	217.26	-19.61	226.23
	2011	0.93	12.47	10.69%	0.95	174.27	-41.49	206.69
	2012	0.98	4.85	2.93%	0.98	224.11	-22.98	217.92
	2013	0.94	13.80	8.68%	0.94	218.90	-24.10	225.38
	2014	0.88	17.49	13.09%	0.88	182.47	-19.55	212.65
	2015	0.98	5.54	3.05%	0.99	223.37	-20.26	214.66
	2016	0.87	18.79	15.48%	0.89	213.44	-17.79	230.21
	2017	1.00	3.85	2.60%	1.00	211.22	-26.23	214.93
	2018	0.91	8.40	4.98%	0.95	213.40	-13.49	207.06
	2019	0.99	3.48	1.77%	1.00	257.49	-16.47	222.51
	2020	0.98	6.14	3.62%	0.98	215.64	-21.26	218.27
	2021	0.98	4.41	2.64%	0.98	217.25	-20.25	225.97
Merlot (ME)	*2009/2021*	*0.67*	*25.97*	*16.05%*	*0.72*	*246.53*	*-11.10*	*215.27*
	2009	0.92	6.58	3.94%	0.96	499.46	-6.92	251.53
	2010	0.97	6.89	4.68%	0.97	232.20	-15.73	226.05
	2011	0.79	15.46	10.60%	0.79	283.00	-12.32	210.77
	2012	0.98	6.65	3.74%	0.99	252.93	-22.56	215.38
	2013	0.95	9.90	6.01%	0.96	229.40	-17.90	223.23
	2014	0.96	9.52	6.71%	0.96	187.63	-21.68	210.09
	2015	0.96	10.37	6.18%	0.97	240.36	-18.33	215.01
	2016	0.94	10.55	6.73%	0.94	376.03	-8.14	245.20
	2017	0.99	4.81	2.69%	0.99	246.40	-18.37	210.07
	2018	0.96	5.88	3.71%	0.97	364.36	-5.73	238.90
	2019	0.85	14.60	7.48%	0.95	239.08	-25.13	220.76
	2020	0.95	10.25	6.77%	0.95	206.43	-21.43	215.31
	2021	0.80	18.52	10.26%	0.80	254.33	-16.30	222.33

R^2= coefficient of determination; EF = modelling efficiency; RMSE = root mean square error; RRMSE = relative root mean square error; *a* is the theoretical maximum value, X_0 is the required days, to reach 50% of *a*, and *b* is the rate of increase in the variable.

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TABLE 2SM. Fit parameters and goodness of fit metrics for the exponential function used to model berry total acidity (TA) levels during the season on a day-of-the-year (DOY) basis (Eq. 2).

Variety	Year	R^2	RMSE (g/L)	RRMSE	EF	a	b
Garganega (GA)	*2009/2021*	*0.8*	*2.6*	*22.92%*	*0.8*	*1.2E+18*	*7.2*
	2009	1.0	0.5	4.91%	1.0	1.3E+17	6.8
	2010	0.9	1.0	9.45%	0.9	1.3E+18	7.2
	2011	1.0	0.9	4.51%	1.0	7.9E+25	10.6
	2012	0.9	1.4	11.35%	0.9	2.1E+28	11.6
	2013	0.9	1.7	12.74%	0.9	1.4E+21	8.5
	2014	1.0	1.2	6.93%	1.0	1.4E+16	6.3
	2015	0.9	0.9	10.44%	1.0	1.2E+15	6.0
	2016	0.9	1.4	10.36%	0.9	1.6E+18	7.2
	2017	1.0	1.4	11.85%	1.0	9.6E+22	9.3
	2018	0.9	1.4	13.35%	0.9	1.6E+17	6.9
	2019	0.9	0.8	8.94%	1.0	1.5E+16	6.4
	2020	0.8	1.0	12.90%	1.0	3.6E+12	4.9
	2021	0.8	0.8	8.03%	0.8	1.5E+13	5.1
Glera (GL)	*2009/2021*	*0.7*	*4.2*	*31.91%*	*0.7*	*1.6E+20*	*8.1*
	2009	1.0	0.5	4.17%	1.0	2.5E+19	7.8
	2010	1.0	0.7	7.12%	1.0	5.7E+23	9.6
	2011	0.9	2.7	14.99%	0.9	9.4E+27	11.5
	2012	0.8	2.9	26.31%	0.8	2.0E+28	11.6
	2013	0.8	3.4	23.28%	0.8	1.2E+23	9.3
	2014	0.9	2.7	13.95%	1.0	4.5E+17	7.0
	2015	1.0	1.8	13.32%	1.0	1.1E+26	10.6
	2016	0.9	3.1	20.97%	0.9	9.4E+25	10.5
	2017	0.8	3.7	26.97%	0.8	6.7E+26	11.0
	2018	0.9	1.5	14.80%	0.9	2.4E+23	9.5
	2019	0.9	1.6	16.96%	0.9	1.8E+22	9.0
	2020	0.9	2.1	17.10%	0.9	3.2E+26	10.8
	2021	0.9	2.0	16.28%	0.9	1.4E+26	10.6
Cabernet Sauv. (CS)	*2009/2021*	*0.7*	*4.5*	*31.21%*	*0.7*	*9.5E+17*	*7.1*
	2009	1.0	0.8	6.80%	1.0	6.7E+17	7.1
	2010	1.0	1.2	10.05%	1.0	7.3E+22	9.2
	2011	1.0	2.3	11.08%	1.0	3.7E+29	12.2
	2012	0.9	1.5	12.54%	0.9	6.5E+23	9.6
	2013	0.9	2.7	17.86%	0.9	1.1E+23	9.2
	2014	0.9	3.3	17.47%	0.9	3.7E+15	6.1
	2015	0.9	1.5	15.37%	0.9	1.4E+20	8.1
	2016	0.9	2.4	13.03%	1.0	2.7E+20	8.1
	2017	1.0	1.8	10.73%	1.0	7.5E+23	9.7
	2018	0.9	1.8	17.27%	0.9	1.3E+18	7.2
	2019	0.9	0.9	8.89%	1.0	6.0E+18	7.5
	2020	0.9	1.9	15.55%	0.9	7.0E+21	8.8
	2021	0.9	0.9	7.84%	0.9	1.8E+17	6.8
Merlot (ME)	*2009/2021*	*0.7*	*3.0*	*27.89%*	*0.7*	*5.8E+16*	*6.7*
	2009	0.8	0.8	8.14%	0.9	1.7E+15	6.0
	2010	0.9	1.0	9.15%	0.9	5.8E+17	7.1
	2011	0.9	1.8	13.89%	0.9	9.7E+23	9.8
	2012	0.9	1.2	11.07%	0.9	1.3E+26	10.7
	2013	0.9	1.8	16.89%	0.9	1.4E+21	8.5
	2014	0.9	1.5	14.77%	0.9	5.1E+14	5.8
	2015	0.9	1.8	18.42%	0.9	1.1E+23	9.4
	2016	0.8	2.1	18.46%	0.8	8.0E+16	6.7
	2017	0.9	1.6	15.40%	0.9	1.3E+23	9.4
	2018	0.9	1.0	11.93%	1.0	2.4E+16	6.6
	2019	0.7	2.0	23.65%	0.8	1.3E+18	7.2
	2020	0.9	1.7	14.41%	0.9	7.0E+21	8.8
	2021	1.0	0.3	3.95%	1.0	1.2E+17	6.8

R^2 = coefficient of determination; EF = modelling efficiency; RMSE = root mean square error; RRMSE = relative root mean square error; where *a* represents an initial value (positive) raised to *a* constant exponent *b* (*b*<0) represents a factor of decay as *x* (DOY).

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TABLE 3SM. Fit parameters and goodness of fit metrics for the three-parameter logistic functions used to model berry pH increments during the season on a day-of-the-year (DOY) basis (Eq. 1).

Variety	Year	R^2	RMSE (g/L)	RRMSE (%)	EF	a (pH)	b	X_0 (DOY)
Garganega (GA)	*2009/2021*	*0.77*	*0.11*	*0.04*	*0.77*	*3.18*	*-11.85*	*187.59*
	2009	0.99	0.02	0.01	0.99	3.30	-9.97	183.11
	2010	0.96	0.07	0.02	0.81	3.18	-13.12	196.78
	2011	0.99	0.03	0.01	0.99	3.73	-8.98	193.26
	2012	0.98	0.03	0.01	0.98	3.19	-22.34	201.47
	2013	0.97	0.03	0.01	0.97	3.10	-18.70	202.45
	2014	0.99	0.03	0.01	0.99	3.26	-10.16	187.49
	2015	0.87	0.05	0.02	0.87	3.25	-13.87	187.60
	2016	0.86	0.08	0.03	0.86	3.31	-10.33	190.48
	2017	0.99	0.04	0.01	0.98	3.31	-12.93	192.97
	2018	0.80	0.07	0.02	0.80	3.19	-14.45	186.33
	2019	0.88	0.05	0.02	0.88	3.21	-10.76	194.74
	2020	0.74	0.07	0.02	0.74	6.77	-1.17	292.70
	2021	0.87	0.03	0.01	0.87	3.09	-13.39	193.94
Glera (GL)	*2009/2021*	*0.64*	*0.16*	*0.06*	*0.64*	*3.27*	*-12.51*	*187.94*
	2009	0.95	0.05	0.02	0.79	3.53	-11.76	190.25
	2010	0.98	0.02	0.01	0.98	3.27	-15.82	197.28
	2011	0.79	0.12	0.04	0.79	3.81	-8.65	189.60
	2012	0.82	0.12	0.04	0.82	3.48	-16.97	198.20
	2013	0.74	0.14	0.05	0.73	3.25	-16.39	200.98
	2014	0.89	0.11	0.04	0.89	3.46	-7.65	185.49
	2015	0.91	0.10	0.03	0.91	3.32	-15.70	192.72
	2016	0.72	0.17	0.06	0.72	3.32	-13.94	199.85
	2017	0.82	0.15	0.05	0.81	3.46	-12.66	191.39
	2018	0.88	0.06	0.02	0.88	3.52	-9.17	181.10
	2019	0.95	0.04	0.01	0.95	3.67	-6.73	193.47
	2020	0.95	0.08	0.03	0.92	3.34	-11.99	193.94
	2021	0.88	0.05	0.02	0.88	3.05	-46.82	211.91
Cabernet Sauv. (CS)	*2009/2021*	*0.66*	*0.21*	*0.07*	*0.66*	*3.52*	*-8.55*	*190.87*
	2009	0.90	0.06	0.02	0.89	3.56	-8.37	185.85
	2010	0.93	0.10	0.03	0.87	3.36	-14.07	206.07
	2011	0.97	0.06	0.02	0.97	3.74	-12.26	197.25
	2012	0.81	0.11	0.04	0.76	3.68	-10.94	202.29
	2013	0.87	0.15	0.05	0.87	3.44	-13.47	208.96
	2014	0.88	0.12	0.04	0.88	3.34	-9.23	188.21
	2015	0.93	0.08	0.03	0.93	3.49	-16.29	199.76
	2016	0.88	0.14	0.05	0.88	4.05	-7.51	212.04
	2017	0.99	0.05	0.02	0.99	3.56	-13.24	200.82
	2018	0.96	0.04	0.01	0.96	3.45	-13.23	190.60
	2019	0.99	0.03	0.01	0.99	3.40	-11.33	204.71
	2020	0.99	0.03	0.01	0.99	3.14	-19.92	204.43
	2021	0.96	0.04	0.02	0.87	3.27	-10.98	199.96
Merlot (ME)	*2009/2021*	*0.70*	*0.16*	*0.05*	*0.70*	*3.57*	*-8.90*	*185.04*
	2009	0.90	0.05	0.02	0.86	4.27	-5.53	189.15
	2010	0.92	0.06	0.02	0.92	4.07	-5.13	189.15
	2011	0.81	0.10	0.03	0.81	3.77	-8.27	183.29
	2012	0.97	0.05	0.02	0.97	3.53	-18.80	201.24
	2013	0.93	0.07	0.02	0.93	3.37	-16.69	202.60
	2014	0.96	0.08	0.03	0.96	3.36	-15.03	191.97
	2015	0.96	0.07	0.02	0.96	3.64	-16.05	197.46
	2016	0.74	0.15	0.05	0.69	3.66	-9.86	200.73
	2017	0.97	0.07	0.02	0.96	3.64	-13.71	193.61
	2018	0.96	0.04	0.01	0.96	3.87	-6.36	177.23
	2019	0.81	0.12	0.04	0.81	3.62	-11.72	202.44
	2020	0.97	0.05	0.02	0.97	3.52	-11.40	193.61
	2021	0.98	0.04	0.01	0.96	3.68	-13.11	198.20

R^2= coefficient of determination; EF = modelling efficiency; RMSE = root mean square error; RRMSE = relative root mean square error; *a* is the theoretical maximum value, X_0 is the required days, to reach 50% of *a*, and b is the rate of increase in the variable.

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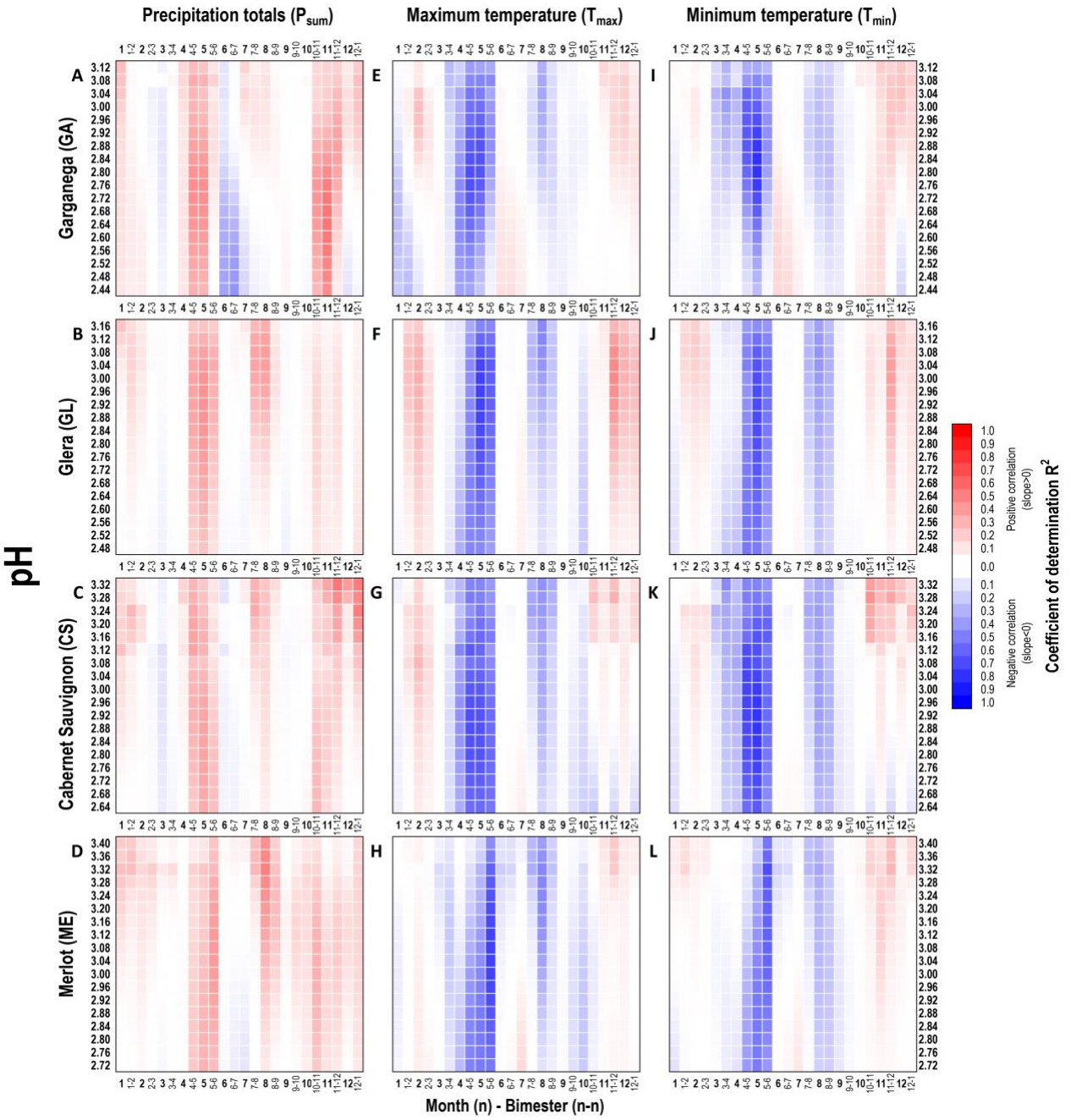


FIGURE 4SM. Heatmaps showing significance (R^2 values) of linear regression analyses performed between anomalies of climate indicators: P_{sum} (A-D), T_{max} (E-H), T_{min} (I-L) and ripening anomalies, expressed as advances or delays in days to 18 target ripening thresholds for berry juice pH in Garganega (A,E,I), Glera (B,F,J), Cabernet sauvignon (C,G,K) and Merlot (D,H,L) during the ripening at different time intervals, reported as annual (Y), month (*n*) or bimester (*n-n*). Colour-scale gradient shows where a positive (red) or negative (blue) slope coefficient was obtained through standard linear regression analysis performed by forcing the intercept to zero (line passing through origin). Slope coefficients (±SE) for most significant relationships (R^2>0.5) are reported as Supplementary materials Tables SM4-9.

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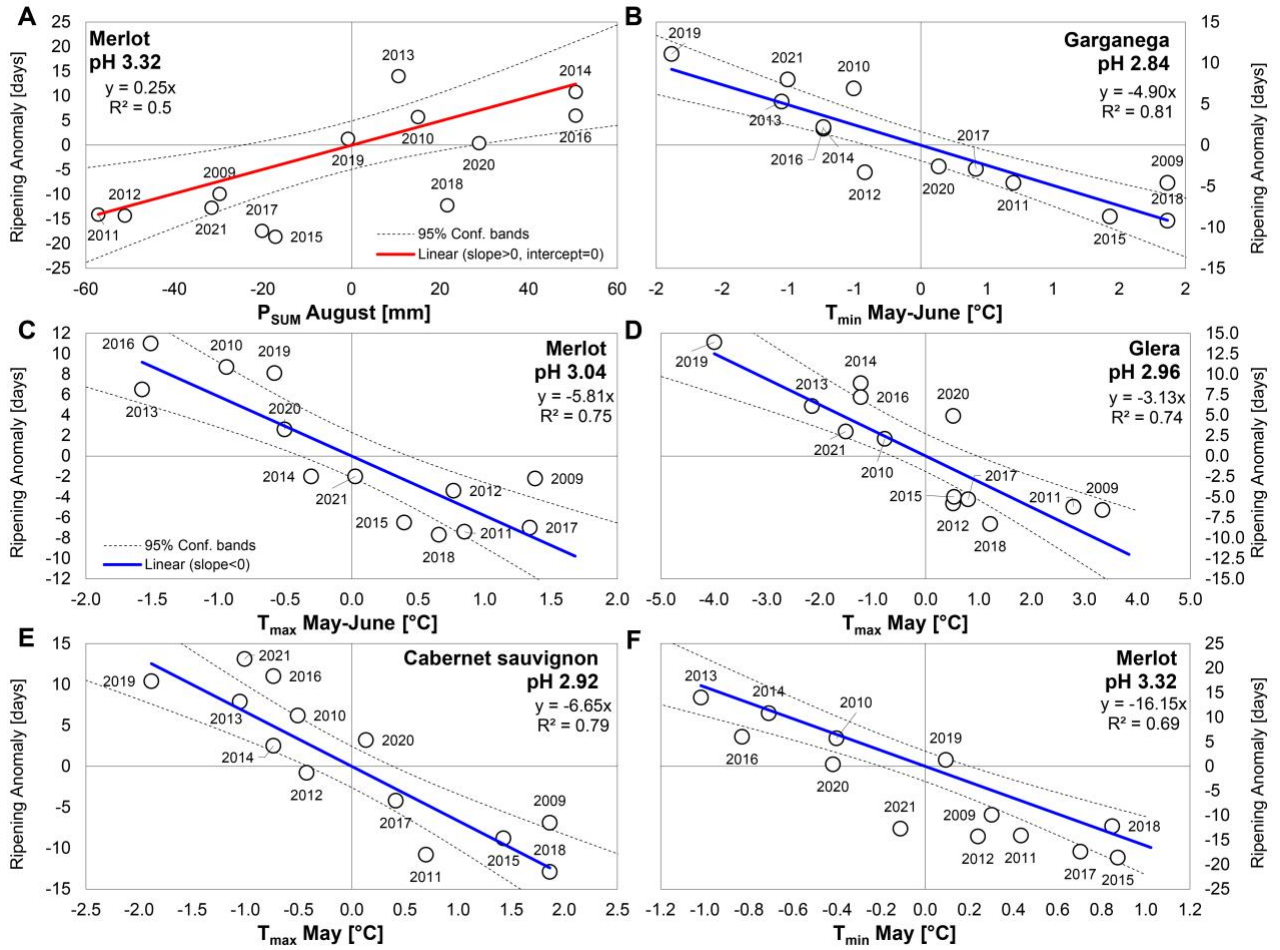


FIGURE 5SM. Six of the most significant relationships obtained by standard linear regression analysis between anomalies of climate indicators (P_{sum}, T_{max}, T_{min}) and specific target thresholds for berry juice pH during the ripening period. Solid lines represent the linear regressions with positive (red) or negative (blue) slope coefficient. Dashed lines represent 95% confidence bands. For each cultivar, advance or delay in days to target each ripening threshold can be easily estimated by multiplying a given climate anomaly unit (mm or °C) per the slope coefficient of the relationship. Slope coefficients (±SE) for most significant relationships (R^2>0.5) are reported as Supplementary material Tables SM4-9.

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Table 4SM. Slope of linear regression functions for cv. Garganega cultivar between climate indicators and ripening anomalies for the 18 thresholds selected during the ripening period (see Table 2).

Ripening variable		**TSS** *(g/L)*				**TA** *(g/L)*						**pH**				
Climate indicator		**P_{SUM}**	**T_{min}**	**T_{min}**		**P_{SUM}**	**T_{max}**	**T_{min}**				**P_{SUM}**	**T_{max}**		**T_{min}**	
month (n) - bimester (n-n)	*g/L*	*8*	*1-2*	*5-6*	*g/L*	*1-2*	*8*	*5-6*	*8*	*11-12*		*11*	*4-5*	*5*	*4-5*	*5*
GARGANEGA	*160*				*5*		*-6.47±1.43*		-6.8±1.95		*3.12*					
Ripening	*155*		5.85±1.5		*6*		*-5.74±1.23*		-6.15±1.66	5.62±1.6	*3.08*					
thresholds	*150*		5.65±1.43		*7*		*-5.14±1.12*	-9.54±2.75	-5.6±1.48	5.08±1.44	*3.04*		-5.28±1.42	-4.19±1.19	-9.25±2.21	-7.33±1.94
	145		*5.46±1.23*		*8*		*-4.63±1.07*	-9.05±2.44	-5.16±1.35		*3.00*		-4.33±1.14	-3.55±0.91	*-7.61±1.74*	*-6.33±1.43*
	140		4.16±1.19		*9*	0.13±0.04	-4.21±1.06	-8.67±2.25	-4.78±1.3		*2.96*		-3.82±0.95	*-3.18±0.75*	*-6.68±1.47*	*-5.75±1.12*
	135	0.17±0.05			*10*	0.13±0.04	-3.82±1.08	-8.33±2.15			*2.92*		*-3.53±0.82*	*-2.94±0.64*	*-6.05±1.3*	***-5.38±0.91***
	130	0.16±0.04			*11*	0.12±0.03		-8.04±2.1			*2.88*		*-3.35±0.72*	*-2.76±0.57*	*-5.58±1.19*	***-5.1±0.76***
	125				*12*	0.12±0.03		-7.75±2.13			*2.84*		*-3.24±0.66*	*-2.64±0.53*	*-5.21±1.16*	**-4.9±0.69**
	120				*13*						*2.80*		*-3.2±0.62*	*-2.55±0.52*	-4.91±1.18	**-4.75±0.68**
	115				*14*						*2.76*		*-3.18±0.63*	*-2.49±0.55*	-4.65±1.27	***-4.63±0.74***
	110			-7.22±2	*15*						*2.72*	0.08±0.02	*-3.17±0.67*	-2.42±0.6		***-4.51±0.86***
	105			-7.27±1.93	*16*						*2.68*	0.08±0.02	*-3.21±0.74*	-2.39±0.67		*-4.45±1*
	100			-7.32±1.92	*17*						*2.64*	0.09±0.02	-3.25±0.82			-4.38±1.16
	95			-7.4±1.95	*18*						*2.60*	0.09±0.03	-3.3±0.93			
	90			-7.45±2.05	*19*						*2.56*	0.1±0.03				

Slope values (± SE) of the most consistent linear regression relationships (intercept = 0), deemed significant with $R^2 > 0.5$, between climate indicators (T_{max}, T_{min}, P_{sum}) for specific time intervals (year, month or bimester) and ripening anomalies for each ripening threshold. Values are formatted according to the consistency of the relationship: $0.5 \leq R^2 < 0.6$ (normal); $0.6 \leq R^2 < 0.7$ (*italic*); $0.7 \leq R^2 < 0.8$ (***bold-italic***) and $R^2 \geq 0.8$ (***red bold-italic***). The empty cells mean that the relationship was not deemed significant ($R^2 < 0.5$). TSS = Totals Soluble Solids (g/L); TA = total acidity (g/L); T_{max} = maximum temperature; T_{min} = minimum temperature, P_{sum} = precipitation totals.

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Table 5SM. Slope of linear regression functions for cv. Glera cultivar between climate indicators and ripening anomalies (TSS, TA) for the 18 thresholds selected during the ripening period (see Table 2).

Ripening variable		**TSS** *(g/L)*								**TA** *(g/L)*							
Climate indicator		**P_{SUM}**		**T_{max}**		**T_{min}**				**T_{max}**				**T_{min}**			
month (n) – bimester (n-n)	*g/L*	*1-2*	*8*	*5-6*	*8*	*1-2*	*5-6*	*8*	*g/L*	*4-5*	*5*	*5-6*	*8*	*4-5*	*5*	*5-6*	*8*
GLERA	*175*		*0.35±0.08*		*-9.52±2.08*	7.1±1.91		-10.1±2.82	*5*								
Ripening	*170*		*0.32±0.07*		*-8.47±1.97*	6.43±1.75		-9.29±2.54	*6*								
thresholds	*165*	0.25±0.06	*0.3±0.07*		-7.49±1.94	5.92±1.63			*7*							-9.93±2.8	
	160	*0.25±0.05*	*0.3±0.06*	-9.96±2.91	*-7.98±1.74*			***-9.95±1.95***	*8*							-9.54±2.48	
	155	*0.21±0.04*	*0.24±0.06*	-8.07±2.39	***-6.74±1.31***		-11.73±3.43	***-8.1±1.6***	*9*							-9.18±2.2	-4.77±1.37
	150	*0.19±0.04*	0.2±0.05	-7.27±2.11	***-6.08±1.14***		-10.69±2.99	***-7.24±1.42***	*10*		-2.64±0.71		-3.83±1.1			*-8.9±2.01*	-4.62±1.26
	145	*0.17±0.04*	0.18±0.05	-6.84±1.9	***-5.63±1.03***		-10.1±2.67	***-6.72±1.28***	*11*		-2.58±0.64	-5±1.35	-3.64±1.04		-4.2±1.14	*-8.62±1.83*	-4.49±1.16
	140	*0.16±0.04*			-4.62±1.12		-9.16±2.51	-5.18±1.4	*12*	-2.88±0.82	*-2.56±0.6*	-4.96±1.26	-3.5±1		-4.18±1.06	*-8.42±1.73*	-4.39±1.1
	135	0.14±0.03			*-4.47±1*		-8.94±2.24	-5.09±1.24	*13*	-2.84±0.77	*-2.51±0.56*	-4.87±1.18			-4.11±0.99	*-8.18±1.63*	-4.26±1.05
	130	0.14±0.03			*-4.32±0.94*		*-8.73±2.07*	*-4.98±1.14*	*14*	-2.82±0.73	*-2.48±0.53*	*-4.8±1.13*			*-4.07±0.94*	*-7.98±1.58*	-4.16±1.02
	125	0.13±0.03			*-4.16±0.91*		*-8.59±1.95*	*-4.87±1.09*	*15*	-2.79±0.71	*-2.46±0.5*	*-4.75±1.09*			*-4.03±0.9*	*-7.79±1.56*	-4.07±0.99
	120	0.12±0.03			*-3.99±0.92*		*-8.41±1.89*	*-4.74±1.06*	*16*	-2.77±0.69	*-2.43±0.49*	*-4.7±1.07*			*-3.99±0.89*	*-7.63±1.55*	-3.99±0.99
	115				-3.85±0.93		*-8.25±1.87*	*-4.62±1.06*	*17*	-2.75±0.68	*-2.4±0.49*	*-4.66±1.05*		-4.29±1.21	*-3.96±0.87*	*-7.48±1.55*	-3.9±0.99
	110				-3.7±0.97		*-8.12±1.9*	-4.5±1.09	*18*	-2.71±0.68	*-2.37±0.49*	*-4.59±1.05*		-4.28±1.2	*-3.91±0.87*	*-7.32±1.58*	-3.83±0.99
	105				-3.58±1.01		-8.02±1.95	-4.41±1.13	*19*	-2.7±0.67	*-2.35±0.49*	*-4.54±1.06*		-4.29±1.18	*-3.88±0.87*	*-7.18±1.62*	-3.75±1.01
	100						-7.92±2.05	-4.33±1.19	*20*	-2.68±0.68	*-2.33±0.5*	*-4.5±1.07*		-4.3±1.18	*-3.85±0.88*	*-7.06±1.66*	-3.69±1.02
	95						-7.78±2.16		*21*	-2.67±0.68	*-2.31±0.5*	-4.48±1.08		-4.32±1.17	*-3.84±0.88*	-6.96±1.69	-3.64±1.04
	90								*22*	-2.65±0.7	*-2.29±0.52*	-4.42±1.11		-4.32±1.18	*-3.81±0.9*	-6.81±1.76	

Slope values (± SE) of the most consistent linear regression relationships (intercept = 0), deemed significant with $R^2 > 0.5$, between climate indicators (T_{max}, T_{min}, P_{sum}) for specific time intervals (year, month or bimester) and ripening anomalies for each ripening threshold. Values are formatted according to the consistency of the relationship: $0.5 \leq R^2 < 0.6$ (normal); $0.6 \leq R^2 < 0.7$ (*italic*); $0.7 \leq R^2 < 0.8$ (***bold-italic***) and $R^2 \geq 0.8$ (***red bold-italic***). The empty cells mean that the relationship was not deemed significant ($R^2 < 0.5$). TSS = Totals Soluble Solids (g/L); TA = total acidity (g/L); T_{max} = maximum temperature; T_{min} = minimum temperature, P_{sum} = precipitation totals.

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Table 6SM. Slope of linear regression functions for cv. Glera cultivar between climate indicators and ripening anomalies (pH) for the 18 thresholds selected during the ripening period (see Table 2).

Ripening variable		pH				
Climate indicator		T_{max}		T_{min}		
month (n) – bimester (n-n)		*5*	*5-6*	*4-5*	*5*	*5-6*
GLERA	*3.16*					
Ripening thresholds	*3.12*	*-4.08±1.01*	-7.69±2.11		-6.73±1.81	
	3.08	*-3.79±0.78*	*-6.99±1.71*		*-6.23±1.43*	-10.21±2.93
	3.04	***-3.55±0.65***	*-6.47±1.5*		*-5.84±1.21*	-9.45±2.59
	3.00	***-3.29±0.56***	*-6.07±1.36*		***-5.4±1.03***	-8.93±2.31
	2.96	***-3.13±0.53***	*-5.78±1.29*		***-5.15±0.97***	-8.5±2.19
	2.92	***-3±0.51***	*-5.51±1.26*		***-4.98±0.92***	-8.11±2.13
	2.88	***-2.91±0.51***	*-5.31±1.26*		***-4.86±0.9***	-7.82±2.12
	2.84	***-2.82±0.52***	-5.12±1.27		***-4.74±0.91***	-7.57±2.12
	2.80	*-2.75±0.54*	-4.97±1.29		*-4.66±0.91*	
	2.76	*-2.69±0.56*	-4.86±1.32		*-4.58±0.94*	
	2.72	*-2.63±0.58*	-4.74±1.35	-4.81±1.37	*-4.52±0.95*	
	2.68	*-2.58±0.61*		-4.87±1.38	*-4.46±1*	
	2.64	-2.54±0.64		-4.95±1.38	*-4.41±1.04*	
	2.60	-2.49±0.67		-5±1.39	-4.35±1.08	
	2.56	-2.45±0.69		-5.08±1.39	-4.31±1.11	
	2.52			-5.14±1.41	-4.27±1.16	
	2.48			-5.23±1.42	-4.25±1.2	

Slope values (± SE) of the most consistent linear regression relationships (intercept = 0), deemed significant with $R^2 > 0.5$, between climate indicators (T_{max}, T_{min}, P_{sum}) for specific time intervals (year, month or bimester) and ripening anomalies for each ripening threshold. Values are formatted according to the consistency of the relationship: $0.5 \leq R^2 < 0.6$ (normal); $0.6 \leq R^2 < 0.7$ (*italic*); $0.7 \leq R^2 < 0.8$ (***bold-italic***) and $R^2 \geq 0.8$ (***red bold-italic***). The empty cells mean that the relationship was not deemed significant ($R^2 < 0.5$). T_{max} = maximum temperature; T_{min} = minimum temperature, P_{sum} = precipitation totals.

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Table 7SM. Slope of liner regression functions for cv. Cabernet Sauvignon cultivar between climate indicators and pH ripening anomalies for the 18 thresholds selected during the ripening period (see Table 2).

Ripening variable		pH							
Climate indicator		P_{SUM}		T_{max}			T_{min}		
month (n) – bimester (n-n)		*11-12*	*12-1*	*4-5*	*5*	*5-6*	*4-5*	*5*	*5-6*
CABERNET SAUV.	*3.32*	0.29±0.09	0.45±0.15						
Ripening thresholds	*3.28*			-7.11±2.31			-12.57±4.16	-9.43±2.97	
	3.24		0.31±0.09		-5.2±1.6			-9.29±2.56	-16.94±4.73
	3.2				-4.71±1.34		-10.84±3.28	*-8.53±2.1*	*-15.32±3.97*
	3.16			-5.57±1.62	-4.37±1.17	-8.09±2.51	-10.14±2.83	*-7.96±1.77*	*-14.12±3.45*
	3.12			*-6.02±1.35*	-4.59±1.16		***-10.23±2.04***	*-8.36±1.71*	-13.73±4
	3.08			-5.09±1.36	-4.18±1.09		***-9.66±1.81***	*-7.79±1.59*	-13.28±3.38
	3.04			*-4.95±1.15*	*-4.02±0.93*		***-8.95±1.6***	***-7.44±1.31***	-12.35±3.02
	3			*-4.8±1.01*	*-3.87±0.83*	-7.05±1.93	***-8.43±1.49***	***-7.14±1.15***	-11.61±2.82
	2.96			*-4.65±0.93*	*-3.74±0.77*	-6.84±1.8	***-8.04±1.41***	***-6.88±1.05***	-11.04±2.69
	2.92			*-4.51±0.88*	*-3.63±0.73*	-6.69±1.69	***-7.69±1.37***	***-6.65±0.99***	-10.58±2.6
	2.88			*-4.4±0.85*	*-3.54±0.71*	-6.58±1.63	***-7.43±1.37***	***-6.48±0.97***	-10.2±2.57
	2.84			*-4.28±0.85*	*-3.45±0.7*	-6.44±1.59	***-7.18±1.37***	***-6.28±0.97***	-9.82±2.56
	2.8			*-4.19±0.85*	*-3.38±0.7*	-6.36±1.57	*-7±1.39*	***-6.14±0.99***	-9.51±2.58
	2.76			*-4.09±0.87*	*-3.32±0.71*	-6.29±1.57	*-6.82±1.44*	***-6.01±1.03***	-9.26±2.62
	2.72			*-4±0.9*	*-3.26±0.73*	-6.19±1.59	*-6.67±1.48*	***-5.87±1.08***	
	2.68			*-3.94±0.93*	*-3.21±0.75*	-6.13±1.61	*-6.54±1.53*	*-5.76±1.14*	
	2.64			-3.86±0.97	-3.16±0.77	-6.06±1.65	-6.42±1.6	*-5.65±1.21*	

Slope values (± SE) of the most consistent linear regression relationships (intercept = 0), deemed significant with $R^2 > 0.5$, between climate indicators (T_{max}, T_{min}, P_{sum}) for specific time intervals (year, month or bimester) and ripening anomalies for each ripening threshold. Values are formatted according to the consistency of the relationship: $0.5 \leq R^2 < 0.6$ (normal); $0.6 \leq R^2 < 0.7$ (*italic*); $0.7 \leq R^2 < 0.8$ (***bold-italic***) and $R^2 \geq 0.8$ (***red bold-italic***). The empty cells mean that the relationship was not deemed significant ($R^2 < 0.5$). TSS = Totals Soluble Solids (g/L); TA = total acidity (g/L); T_{max} = maximum temperature; T_{min} = minimum temperature, P_{sum} = precipitation totals.

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Table 8SM. Slope of linear regression functions for cv. Merlot cultivar between climate indicators and ripening (TSS, TA) anomalies for the 18 thresholds selected during the ripening period (see Table 2).

Ripening variable		**TSS** *(g/L)*								**TA** *(g/L)*				
Climate indicator		**P_{SUM}**		**T_{max}**				**T_{min}**		**P_{SUM}**	**T_{max}**		**T_{min}**	
month (n) – bimester (n-n)	*g/L*	*7-8*	*8*	*3-4*	*5-6*	*7-8*	*8*	*8*	*g/L*	*8*	*5-6*	*8*	*5-6*
MERLOT	*230*	0.3±0.13					-10.94±2.74		*5*	0.23±0.06		-6.28±1.57	
Ripening thresholds	*225*	0.27±0.11	0.33±0.09				-9.51±2.31		*6*	0.2±0.05		-5.57±1.36	-11.04±3.05
	220	*0.25±0.1*	0.31±0.08				*-8.59±2*		*7*	0.18±0.05	-6.44±1.7	-5±1.2	-10.36±2.55
	215	*0.5±0.13*	*0.32±0.08*				*-8.08±1.93*		*8*	0.17±0.04	*-6.19±1.43*	-4.53±1.1	*-9.79±2.19*
	210	*0.45±0.12*	*0.3±0.07*			-10.5±3.28	*-7.48±1.67*		*9*	0.15±0.04	*-5.96±1.22*	-4.12±1.03	*-9.3±1.91*
	205	0.37±0.09	*0.28±0.06*			-9.82±2.84	*-6.99±1.48*		*10*	0.14±0.04	***-5.76±1.05***	-3.76±0.99	***-8.88±1.69***
	200	0.32±0.09	*0.25±0.05*			-8.84±2.61	***-6.56±1.25***		*11*	0.13±0.04	***-5.58±0.94***	-3.45±0.97	***-8.48±1.57***
	195		*0.23±0.05*				***-6.2±1.12***		*12*		***-5.41±0.86***		***-8.14±1.5***
	190		*0.22±0.05*				***-5.87±1***		*13*		***-5.28±0.82***		***-7.86±1.47***
	185		*0.19±0.04*		-6.06±1.68		***-5.58±0.83***	-5.31±1.48	*14*		***-5.15±0.81***		*-7.59±1.49*
	180		*0.17±0.04*		-5.84±1.49		***-5.1±0.8***		*15*		***-5.02±0.83***		*-7.33±1.52*
	175		0.16±0.04		*-5.69±1.34*		***-4.76±0.79***		*16*		***-4.9±0.86***		*-7.05±1.59*
	170		0.14±0.04	-4.55±1.3	*-5.59±1.24*		***-4.49±0.79***		*17*		***-4.82±0.9***		-6.87±1.67
	165			-4.49±1.23	*-5.5±1.15*		***-4.26±0.8***		*18*		*-4.71±0.96*		-6.66±1.75
	160			-4.43±1.18	*-5.46±1.09*		*-4.07±0.81*		*19*		*-4.61±1.02*		-6.45±1.84
	155			-4.35±1.16	*-5.44±1.04*		*-3.91±0.84*		*20*		*-4.54±1.08*		
	150			-4.25±1.17	***-5.41±1.02***		*-3.75±0.88*		*21*		-4.46±1.14		
	145				***-5.4±1.01***		-3.62±0.91		*22*		-4.38±1.19		

Slope values (± SE) of the most consistent linear regression relationships (intercept = 0), deemed significant with $R^2 > 0.5$, between climate indicators (T_{max}, T_{min}, P_{sum}) for specific time intervals (month number or bimester) and ripening anomalies for each ripening threshold. Values are formatted according to the consistency of the relationship: $0.5 \leq R^2 < 0.6$ (normal); $0.6 \leq R^2 < 0.7$ (*italic*); $0.7 \leq R^2 < 0.8$ (***bold-italic***) and $R^2 \geq 0.8$ (***red bold-italic***). The empty cells mean that the relationship was not deemed significant ($R^2 < 0.5$). TSS = Totals Soluble Solids (g/L); TA = total acidity (g/L); T_{max} = maximum temperature; T_{min} = minimum temperature, P_{sum} = precipitation totals.

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Table 9SM. Slope of linear regression functions for cv. Merlot cultivar between climate indicators and pH ripening anomalies for the 18 thresholds selected during the ripening period (see Table 2).

Ripening variable		pH			
Climate indicator		T_{max}		T_{min}	
month (n) – bimester (n-n)		*5*	*5-6*	*5*	*5-6*
MERLOT	*3.4*				-21.47±6.37
Ripening thresholds	*3.36*		-10.66±3.27		-18.97±5.05
	3.32		*-9.74±2.22*		*-16.15±3.1*
	3.28		*-8.3±1.77*		*-12.96±2.77*
	3.24		*-7.49±1.52*		*-11.28±2.55*
	3.2		*-6.94±1.33*		*-10.18±2.33*
	3.16		***-6.55±1.19***		*-9.43±2.18*
	3.12		***-6.25±1.08***		*-8.89±2.04*
	3.08		***-6±1.01***		*-8.45±1.96*
	3.04		***-5.82±0.98***		*-8.11±1.93*
	3		***-5.64±0.97***		-7.85±1.91
	2.96		***-5.51±1***	-3.9±1.11	-7.63±1.94
	2.92	-2.29±0.66	*-5.39±1.04*	-3.91±1.1	-7.42±1.99
	2.88	-2.33±0.65	*-5.32±1.1*	-3.98±1.1	-7.31±2.06
	2.84	-2.36±0.66	*-5.21±1.17*	-4.02±1.11	
	2.8	-2.39±0.67	-5.13±1.24	-4.06±1.12	
	2.76	-2.44±0.69	-5.1±1.33	-4.15±1.16	
	2.72	-2.47±0.7	-5.03±1.39	-4.2±1.18	

Slope values (± SE) of the most consistent linear regression relationships (intercept = 0), deemed significant with $R^2 > 0.5$, between climate indicators (T_{max}, T_{min}, P_{sum}) for specific time intervals (month or bimester) and ripening anomalies for each ripening threshold. Values are formatted according to the consistency of the relationship: $0.5 \leq R^2 < 0.6$ (normal); $0.6 \leq R^2 < 0.7$ (*italic*); $0.7 \leq R^2 < 0.8$ (***bold-italic***) and $R^2 \geq 0.8$ (***red bold-italic***). The empty cells mean that the relationship was not deemed significant ($R^2 < 0.5$). TSS = Totals Soluble Solids (g/L); TA = total acidity (g/L); T_{max} = maximum temperature; T_{min} = minimum temperature, P_{sum} = precipitation totals.

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Table 10SM. Comparative analysis of the coefficients of determination of a selection of the most significant relationships (R^2 higher than 0.5) obtained by standard linear regression analysis between the anomalies of climate indicators (P_{sum}, T_{max}, T_{min}), as compared to the average 13 years (2009-2021) time period used in the present study and a long-term time series (1992-2021) available from the same weather station, and specific target thresholds for berry TSS and TA.

Cv.	TSS g/L	Climate variable month (n) – bimester (n-n)	2009-2021 (R^2)	1992-2021 (R^2)	Cv.	TA g/L	Climate variable month (n) – bimester (n-n)	2009-2021 (R^2)	1992-2021 (R^2)
GA	135	P_{sum} (8)	0.53	0.53	GA	6	T_{max} (8)	0.64	0.67
GL	160	P_{sum} (8)	0.58	0.61		11	T_{min} (5-6)	0.56	0.53
	150	T_{max} (8)	0.68	0.68		8	T_{min} (8)	0.55	0.5
	125	T_{min} (5-6)	0.62	0.41	GL	17	T_{max} (5)	0.67	0.62
	155	T_{min} (8)	0.54	0.5		11	T_{max} (8)	0.51	0.58
CS	150	T_{max} (5-6)	0.63	0.63		9	T_{min} (5-6)	0.62	0.63
	180	T_{max} (8)	0.71	0.77		10	T_{min} (8)	0.53	0.55
	170	T_{min} (5-6)	0.63	0.65	CS	19	T_{max} (5-6)	0.69	0.69
	185	T_{min} (8)	0.72	0.79		10	T_{max} (8)	0.6	0.63
ME	185	P_{sum} (8)	0.68	0.66		18	T_{min} (5-6)	0.76	0.69
	145	T_{max} (5-6)	0.7	0.7		12	T_{min} (8)	0.69	0.72
	180	T_{max} (8)	0.79	0.73	ME	8	P_{sum} (8)	0.57	0.56
						13	T_{max} (5-6)	0.78	0.77
						7	T_{max} (8)	0.59	0.6
						10	T_{min} (5-6)	0.7	0.69

* GA Garganega, GL Glera, CS Cabernet Sauvignon, ME Merlot, TSS total soluble solids, TA total acidity.