

TABLE S1. For each period (bd-bloom: budburst-blooming, bloom-ver: blooming-véraison, ver-rip: véraison-technological ripening) the table shows the starting and the ending DOY for each growing season.

Site	alt	Pheno	DOY 2017	DOY 2018	DOY 2019
Ep_1	542	bd-bloom	92	109	105
Ep_1	542	bloom-ver	151	152	164
Ep_1	542	ver-rip	210	213	224
Ep_2	569	bd-bloom	93	109	107
Ep_2	569	bloom-ver	155	152	167
Ep_2	569	ver-rip	212	215	226
Na_1	419	bd-bloom	91	106	101
Na_1	419	bloom-ver	146	149	160
Na_1	419	ver-rip	200	206	216
Na_2	650	bd-bloom	94	110	109
Na_2	650	bloom-ver	156	155	166
Na_2	650	ver-rip	211	219	228
Te_1	279	bd-bloom	91	105	98
Te_1	279	bloom-ver	143	145	156
Te_1	279	ver-rip	199	207	216
Te_2	670	bd-bloom	93	108	100
Te_2	670	bloom-ver	151	-	164
Te_2	670	ver-rip	209	-	221
Tr_1	223	bd-bloom	91	103	102
Tr_1	223	bloom-ver	140	144	154
Tr_1	223	ver-rip	199	202	215
Tr_2	730	bd-bloom	92	110	107
Tr_2	730	bloom-ver	153	156	169
Tr_2	730	ver-rip	210	219	226

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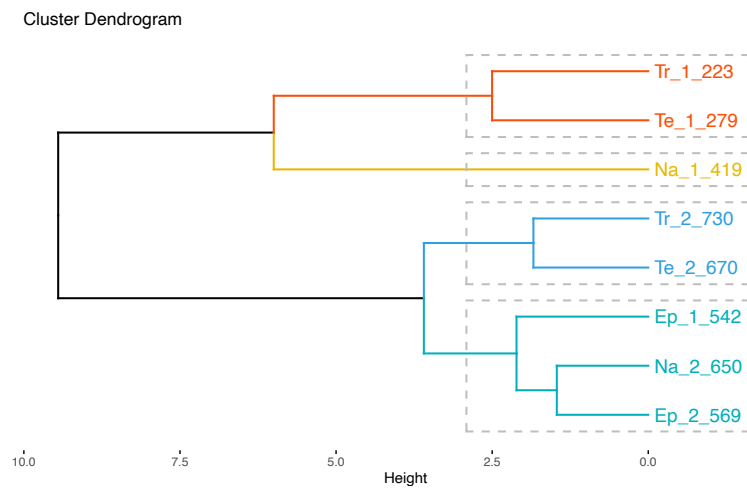


FIGURE S1. Hierarchical cluster analysis.

Sites were classified based on mean and cumulative temperatures and potential radiation measured for the growing seasons and for each phenological stage as mean of the three years.

TABLE S2. Value for grape berry compounds measured along the developmental stage, mean of three replications.

Year	Site	DOY	TSS (g/L)	pH	Tot. ac. (g/L)	YAN (mg/L)	Amino N (mg/L)	Ammonium N (mg/L)	Malic ac. (g/L)	Tartaric ac. (g/L)	Kalium (g/L)	Berry Weight (g)
2017	Ep_2	229	173.82	2.96	14.35	166.00	88.67	76.67	8.17	8.97	1.29	1.76
2017	Ep_2	241	205.80	3.20	8.73	180.00	103.33	72.33	3.90	7.83	1.48	1.83
2017	Ep_2	255	221.62	3.26	6.91	158.33	110.00	48.33	2.73	7.53	1.43	1.58
2017	Ep_1	220	126.53	2.83	19.74	183.67	93.00	90.00	12.43	10.33	1.59	0.00
2017	Ep_1	236	203.37	3.13	10.09	221.33	143.67	77.67	5.13	8.47	1.48	1.91
2017	Ep_1	241	235.43	3.30	8.70	243.67	157.00	80.67	3.77	8.30	1.76	1.68
2017	Na_2	229	244.52	2.99	13.61	79.33	54.67	23.67	8.20	8.43	1.31	1.48
2017	Na_2	241	167.17	3.24	8.25	102.00	61.67	32.67	3.83	7.27	1.51	1.56
2017	Na_2	255	209.44	3.32	6.28	85.33	63.67	21.67	2.57	7.23	1.41	1.33
2017	Na_1	220	219.74	3.09	10.80	175.00	92.67	80.33	5.43	8.67	1.53	0.00
2017	Na_1	236	171.50	3.28	7.20	187.00	121.00	65.33	2.83	8.00	1.58	1.58
2017	Na_1	241	220.73	3.38	6.35	195.67	123.00	66.00	2.03	7.63	1.67	1.54
2017	Te_2	229	232.90	2.95	12.90	99.00	54.33	43.00	7.20	8.37	1.20	1.58
2017	Te_2	241	227.13	3.20	8.10	127.67	73.00	47.67	3.50	7.53	1.43	1.64
2017	Te_2	255	175.08	3.27	6.17	94.00	67.00	27.00	2.20	7.30	1.35	1.41
2017	Te_1	220	212.30	3.19	9.53	135.33	81.00	52.00	4.60	8.60	1.60	0.00
2017	Te_1	236	214.43	3.37	6.16	104.33	74.33	30.00	2.40	7.70	1.62	1.50
2017	Te_1	241	201.40	3.53	5.13	120.67	79.33	35.33	1.50	7.37	1.77	1.33
2017	Tr_2	229	230.60	3.03	13.69	243.33	126.00	117.00	8.53	8.13	1.38	1.74
2017	Tr_2	241	240.05	3.26	8.13	248.67	147.00	95.33	3.97	7.33	1.53	1.82
2017	Tr_2	255	208.30	3.34	6.42	227.00	155.67	71.33	2.83	7.03	1.54	1.62
2017	Tr_1	220	175.00	3.27	8.41	181.00	111.33	68.33	3.43	8.87	1.69	0.00
2017	Tr_1	236	209.80	3.37	6.04	163.67	112.67	50.00	1.93	8.20	1.64	1.66
2017	Tr_1	241	216.93	3.53	4.99	189.00	127.33	55.00	1.23	7.57	1.78	1.55
2018	Ep_2	233	206.40	3.38	5.37	106.00	75.00	31.00	1.37	7.78	1.40	0.00
2018	Ep_2	235	232.90	3.12	7.33	62.00	45.67	16.67	2.62	7.82	1.03	0.00
2018	Ep_2	241	223.53	3.17	6.51	79.67	55.00	23.00	2.00	7.51	1.06	1.40
2018	Ep_2	255	216.39	3.29	5.40	86.00	62.33	22.67	1.40	7.39	1.20	1.44
2018	Ep_1	226	197.69	3.01	10.74	110.33	53.00	57.33	4.86	9.06	1.05	0.00
2018	Ep_1	233	210.07	3.17	7.45	128.00	82.67	45.00	2.76	8.12	1.10	0.00
2018	Ep_1	241	228.99	3.24	6.24	38.33	98.67	38.33	2.23	7.30	1.07	1.53
2018	Ep_1	247	221.18	3.30	5.76	133.33	100.67	33.33	1.97	7.34	1.19	1.61
2018	Na_2	241	178.37	3.07	9.16	55.33	40.67	13.33	4.14	8.05	1.04	1.35
2018	Na_2	257	206.85	3.33	6.21	71.00	54.67	16.00	2.24	6.63	1.25	1.54
2018	Na_1	226	220.30	3.17	6.45	45.67	18.33	27.33	1.59	8.06	1.06	0.00
2018	Na_1	233	238.74	3.24	5.19	48.67	30.67	16.67	0.95	7.60	1.09	0.00
2018	Na_1	241	236.42	3.29	4.24	18.33	44.67	18.33	0.63	6.67	1.00	1.19
2018	Na_1	247	203.27	3.32	4.26	51.33	39.00	12.67	0.70	6.98	1.04	1.32
2018	Te_1	226	237.06	3.26	6.30	73.67	39.00	34.67	2.18	7.47	1.21	0.00
2018	Te_1	233	228.03	3.18	7.35	127.67	81.67	45.67	2.77	8.01	1.16	0.00
2018	Te_1	235	196.19	3.40	4.79	70.00	56.00	15.33	1.52	6.94	1.33	0.00
2018	Tr_2	241	217.07	3.12	7.63	104.00	66.67	36.67	2.91	7.77	1.02	1.38
2018	Tr_2	257	229.86	3.29	6.37	117.00	76.67	39.67	2.02	7.04	1.23	1.56
2018	Tr_1	226	219.90	3.26	6.65	87.33	52.33	35.00	1.94	8.27	1.27	0.00
2018	Tr_1	233	216.19	3.37	5.47	104.67	76.67	27.00	1.35	7.92	1.35	0.00
2019	Ep_2	246	235.67	3.08	10.35	82.00	51.67	31.00	5.76	7.26	0.96	0.00
2019	Ep_2	253	240.39	3.16	8.56	99.67	69.00	32.00	4.50	6.93	0.99	1.31
2019	Ep_2	260	248.41	3.22	7.67	82.00	55.33	25.67	3.60	6.77	1.05	1.90
2019	Ep_2	267	233.56	3.24	6.98	95.00	67.33	27.00	3.09	6.88	1.01	2.12
2019	Ep_2	276	212.07	3.32	6.56	109.00	82.67	30.33	2.83	7.19	1.04	1.85
2019	Ep_1	239	243.90	3.21	9.56	164.00	93.33	68.67	5.18	7.13	1.17	0.00
2019	Ep_1	246	242.57	3.20	9.80	211.33	133.33	78.33	5.36	8.05	1.21	0.00
2019	Ep_1	253	224.46	3.25	8.60	213.00	143.00	69.67	4.33	7.90	1.14	1.85

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2019	Ep_1	260	240.44	3.33	7.72	220.67	155.67	66.67	3.69	7.85	1.34	1.83
2019	Ep_1	267	245.48	3.37	7.49	234.67	172.00	64.00	3.66	7.85	1.34	2.06
2019	Na_2	256	230.05	3.37	9.06	144.00	99.33	49.33	5.02	8.24	1.61	1.54
2019	Na_2	260	203.70	3.25	7.07	39.33	29.33	10.67	3.02	6.79	1.03	2.45
2019	Na_2	267	215.88	3.24	6.96	59.67	46.33	13.33	3.19	6.71	0.98	1.96
2019	Na_2	276	228.22	3.32	5.96	59.33	45.00	17.00	2.36	6.90	1.00	1.64
2019	Na_1	232	241.63	3.04	10.18	89.33	52.67	36.67	4.46	8.23	0.88	0.00
2019	Na_1	239	232.55	3.24	7.15	105.00	63.33	40.67	3.01	6.54	1.02	0.00
2019	Na_1	246	203.83	3.30	5.75	82.33	59.00	25.33	2.14	6.72	0.99	0.00
2019	Na_1	253	197.27	3.38	5.12	92.00	69.00	24.00	1.72	6.75	1.07	1.72
2019	Te_2	253	218.23	3.14	9.29	129.33	86.33	42.67	4.78	7.47	1.02	1.80
2019	Te_2	260	173.82	3.27	8.06	136.00	94.33	40.33	3.63	7.42	1.13	2.73
2019	Te_2	263	205.80	3.28	7.20	122.67	87.33	36.00	2.88	7.66	0.98	1.67
2019	Te_1	232	221.62	3.06	11.36	136.00	76.67	59.33	6.03	7.85	1.04	0.00
2019	Te_1	239	126.53	3.11	12.05	185.00	104.67	78.00	6.76	7.84	1.20	0.00
2019	Te_1	246	203.37	3.36	6.33	123.00	81.67	42.00	2.81	6.94	1.16	0.00
2019	Te_1	253	235.43	3.41	5.76	107.33	79.00	28.67	2.40	7.00	1.21	1.67
2019	Tr_2	256	244.52	3.18	11.70	104.00	67.67	39.00	6.38	9.40	1.56	1.61
2019	Tr_2	263	167.17	3.26	6.25	79.33	53.67	27.33	2.24	7.34	0.94	1.63
2019	Tr_2	269	173.82	3.27	6.30	105.67	71.67	33.00	2.45	7.03	1.07	2.00
2019	Tr_2	276	205.80	3.35	6.20	158.00	107.67	52.00	2.25	7.63	1.19	1.72
2019	Tr_1	232	221.62	3.08	10.64	148.33	87.00	61.33	4.88	8.47	1.06	0.00
2019	Tr_1	239	126.53	3.28	7.39	161.33	94.67	64.67	2.93	7.35	1.22	0.00
2019	Tr_1	246	203.37	3.40	5.73	131.00	92.33	41.67	2.13	7.25	1.23	0.00
2019	Tr_1	253	235.43	3.41	5.64	142.33	100.00	44.00	2.01	7.30	1.23	1.53

YAN = Yeast assimilable nitrogen.

TABLE S3. Predicted value for grape berry compounds at the technological ripening date (DOY220).

Site	Year	DOY220	TSS (g/L)	pH		Tot. ac. (g/L)		YAN (mg/L)		AminoN (mg/L)		AmmoniumN (mg/L)		Malic ac. (g/L)		Tartaric ac. (g/L)		Kalium (g/L)	
				Value	R2	Value	R2	Value	R2	Value	R2	Value	R2	Value	R2	Value	R2	Value	R2
Ep_1	2017	243	220	3.23	0.94	9.44	0.83	206.36	0.02	137.45	0.56	67.33	0.72	3.82	0.96	8.43	0.79	1.64	0.10
Ep_2	2017	253	220	3.25	0.89	7.07	0.90	180.65	0.05	97.66	0.02	59.06	0.60	2.86	0.91	7.55	0.89	1.51	0.61
Na_1	2017	239	220	3.31	0.91	7.25	0.85	178.70	0.01	115.51	0.74	61.43	0.94	2.75	0.90	8.05	0.75	1.59	0.54
Na_2	2017	252	220	3.30	0.92	6.67	0.93	90.20	0.14	63.21	0.39	24.71	0.40	2.79	0.96	7.19	0.66	1.45	0.07
Te_1	2017	237	220	3.40	0.92	6.37	0.88	130.04	0.03	83.98	0.24	38.82	0.62	2.34	0.89	7.72	0.79	1.66	0.51
Te_2	2017	247	220	3.20	0.92	7.87	0.94	112.52	0.02	71.79	0.43	36.63	0.65	2.85	0.98	7.56	0.88	1.33	0.50
Tr_1	2017	236	220	3.39	0.72	6.11	0.84	165.73	0.33	111.33	0.05	51.38	0.54	2.02	0.77	7.99	0.83	1.67	0.14
Tr_2	2017	251	220	3.31	0.92	7.04	0.92	233.24	0.35	153.23	0.24	78.03	0.87	3.16	0.95	7.15	0.94	1.53	0.83
Ep_1	2018	243	220	3.26	0.98	6.96	0.78	120.54	0.13	94.53	0.82	40.03	0.27	2.41	0.83	7.60	0.80	1.20	0.77
Ep_2	2018	241	220	3.22	0.09	6.30	0.34	79.26	0.05	56.40	0.06	22.17	0.00	1.85	0.29	7.67	0.15	1.14	0.00
Na_1	2018	239	220	3.27	0.88	4.75	0.86	43.16	0.01	34.33	0.76	17.91	0.76	0.81	0.76	7.25	0.75	1.04	0.17
Na_2	2018	254	220	3.26	0.98	6.84	0.98	53.33	0.28	40.40	0.11	13.26	0.01	2.52	0.98	7.15	0.95	1.16	0.86
Te_1	2018	229	220	3.28	0.68	6.14	0.63	77.35	0.07	51.41	0.14	30.78	0.33	2.08	0.71	7.43	0.42	1.21	0.54
Tr_1	2018	225	220	3.26	0.91	6.25	0.80	91.36	0.04	55.46	0.28	30.75	0.32	1.80	0.69	8.24	0.62	1.27	0.46
Tr_2	2018	250	220	3.22	0.97	7.00	0.98	116.82	0.06	75.44	0.25	40.79	0.50	2.42	0.98	7.47	0.87	1.10	0.92
Ep_1	2019	256	220	3.30	0.61	8.20	0.21	212.41	0.59	148.76	0.74	67.22	0.00	4.06	0.24	7.85	0.03	1.27	0.62
Ep_2	2019	258	220	3.20	0.89	8.06	0.83	88.40	0.46	60.88	0.69	28.07	0.00	3.87	0.74	7.04	0.01	1.01	0.40
Na_1	2019	246	220	3.29	0.94	6.29	0.92	89.87	0.01	62.40	0.72	29.33	0.73	2.21	0.99	6.91	0.58	1.01	0.73
Na_2	2019	259	220	3.28	0.01	7.76	0.74	99.56	0.38	57.77	0.13	31.86	0.39	4.04	0.78	7.23	0.25	1.24	0.39
Te_1	2019	246	220	3.31	0.90	7.39	0.79	124.23	0.29	81.83	0.00	42.52	0.61	3.21	0.83	7.19	0.63	1.16	0.72
Te_2	2019	254	220	3.16	0.92	9.02	0.95	128.88	0.07	86.75	0.01	41.43	0.30	4.58	0.97	7.46	0.09	1.03	0.05
Tr_1	2019	246	220	3.34	0.87	6.47	0.81	138.03	0.21	91.33	0.01	47.73	0.53	2.32	0.89	7.33	0.68	1.20	0.67
Tr_2	2019	266	220	3.27	0.80	7.35	0.53	104.78	0.32	70.47	0.41	35.50	0.06	3.11	0.69	7.73	0.32	1.23	0.35

YAN = Yeast assimilable nitrogen.

SUPPLEMENTARY DATA

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TABLE S4. Must compounds of vintage 2017, 2018 and 2019, mean of three replications.

Year	Site	TSS (g/L)	pH	Tot. ac. (g/L)	Malic ac. (g/L)	Tartaric ac. (g/L)	Amino N (mg/L)	Ammonium N (mg/L)	YAN (mg/L)	Kalium (g/L)
2017	Ep_2	221.39	3.24	7.54	3.33	6.87	120.67	47.67	168.33	1.47
2017	Ep_1	254.97	3.31	8.07	4.23	6.77	177.33	64.67	242.00	1.77
2017	Na_2	249.60	3.31	6.69	3.83	5.00	91.67	10.00	101.67	1.56
2017	Na_1	237.75	3.39	6.14	2.63	6.67	133.00	50.67	183.67	1.69
2017	Te_2	250.16	3.28	6.67	3.23	6.23	29.00	126.33	97.33	0.00
2017	Te_1	236.34	3.43	4.79	2.43	5.43	93.33	22.33	115.67	1.51
2017	Tr_2	238.11	3.34	7.28	4.00	6.63	67.67	258.33	190.67	0.00
2017	Tr_1	228.50	3.49	4.97	1.97	6.63	139.67	51.33	191.00	1.66
2018	Ep_2	247.99	3.36	5.37	1.76	5.67	57.00	20.67	78.67	1.31
2018	Ep_1	245.72	3.38	5.92	2.52	6.96	132.00	42.67	176.67	1.41
2018	Na_2	240.28	3.36	5.37	2.10	5.66	43.67	14.00	55.67	1.24
2018	Na_1	243.40	3.33	3.94	0.71	5.93	42.00	16.33	61.33	1.24
2018	Te_1	240.97	3.46	3.47	1.49	4.81	60.67	16.00	77.67	1.19
2018	Tr_2	244.31	3.36	6.07	2.21	6.51	77.00	37.67	116.67	1.38
2018	Tr_1	237.97	3.36	5.15	1.85	6.63	77.00	26.33	102.33	1.28
2019	Ep_2	254.67	3.31	6.65	3.55	5.47	96.00	26.67	123.00	1.12
2019	Ep_1	252.24	3.41	7.97	4.52	7.22	194.33	60.33	254.33	1.45
2019	Na_2	252.15	3.31	5.68	2.57	5.24	56.33	17.00	75.00	0.94
2019	Na_1	241.29	3.56	4.10	2.45	4.60	125.00	34.33	159.33	1.24
2019	Te_2	252.98	3.30	7.58	3.76	6.88	93.00	35.00	130.33	1.26
2019	Te_1	252.15	3.49	5.09	2.58	5.40	96.00	33.33	129.00	1.24
2019	Tr_2	245.44	3.34	5.62	2.76	5.21	96.67	39.00	137.33	1.03
2019	Tr_1	242.78	3.51	4.99	2.11	6.19	115.00	40.00	155.33	1.33

YAN = Yeast assimilable nitrogen.

SUPPLEMENTARY DATA

Michelini, S., Tomada, S., Kadison, A. E., Pichler, F., Hinz, F., Zejfart, M., Iannone, F., Lazazzara, V., Sanoll, C., Robatscher, P., Pedri, U., & Haas, F. (2021). Modeling malic acid dynamics to ensure quality, aroma and freshness of Pinot blanc wines in South Tyrol (Italy). *OENO One*, 55(2). <https://doi.org/10.20870/oenone.2021.55.2.4570>

TABLE S5. Stable isotopic carbon fraction of wines, $^{13}\text{C}/^{12}\text{C}$, mean of three replications

Year	Site	$^{13}\text{C}/^{12}\text{C}$
2017	Ep_2	-28.9
2017	Ep_1	-28.2
2017	Na_2	-29.7
2017	Na_1	-29.0
2017	Te_2	-29.8
2017	Te_1	-29.1
2017	Tr_2	-29.0
2017	Tr_1	-28.8
2018	Ep_2	-27.4
2018	Ep_1	-27.2
2018	Na_2	-28.1
2018	Na_1	-26.2
2018	Te_2	NA
2018	Te_1	-28.2
2018	Tr_2	-27.6
2018	Tr_1	-28.3
2019	Ep_2	-29.2
2019	Ep_1	-28.9
2019	Na_2	-28.4
2019	Na_1	-27.0
2019	Te_2	-29.5
2019	Te_1	-28.9
2019	Tr_2	-27.2
2019	Tr_1	-29.3

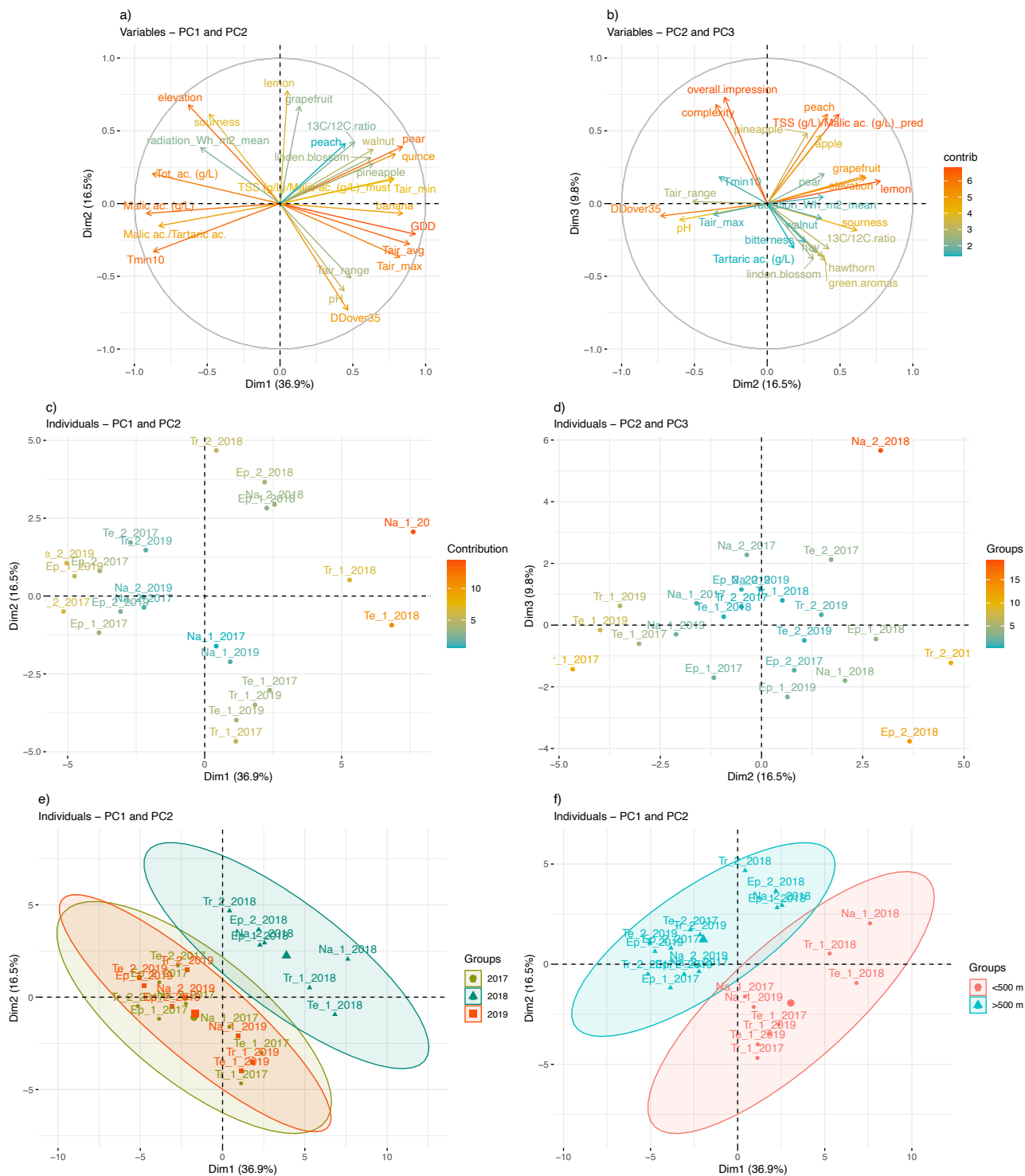


FIGURE S2. Variable (a and b) and individual (c, d, e and f) contribution to PC1 and PC2 (a, c, e and f) and PC2 and PC3 (b, d).

^aThe 20 most contributing variables to PC1 and PC2 are drawn and colored according to their contribution score. ^bThe 20 most contributing variables to PC2 and PC3 are drawn and colored according to their contribution score. ^cIndividual contribution to PC1 and PC2 are drawn and colored according to their contribution score. ^dIndividual contribution to PC1 and PC2 are drawn and colored according to their contribution score. ^eAnd ^fresemble figure ^cwith individual colored and grouped by vintage and elevation range respectively.

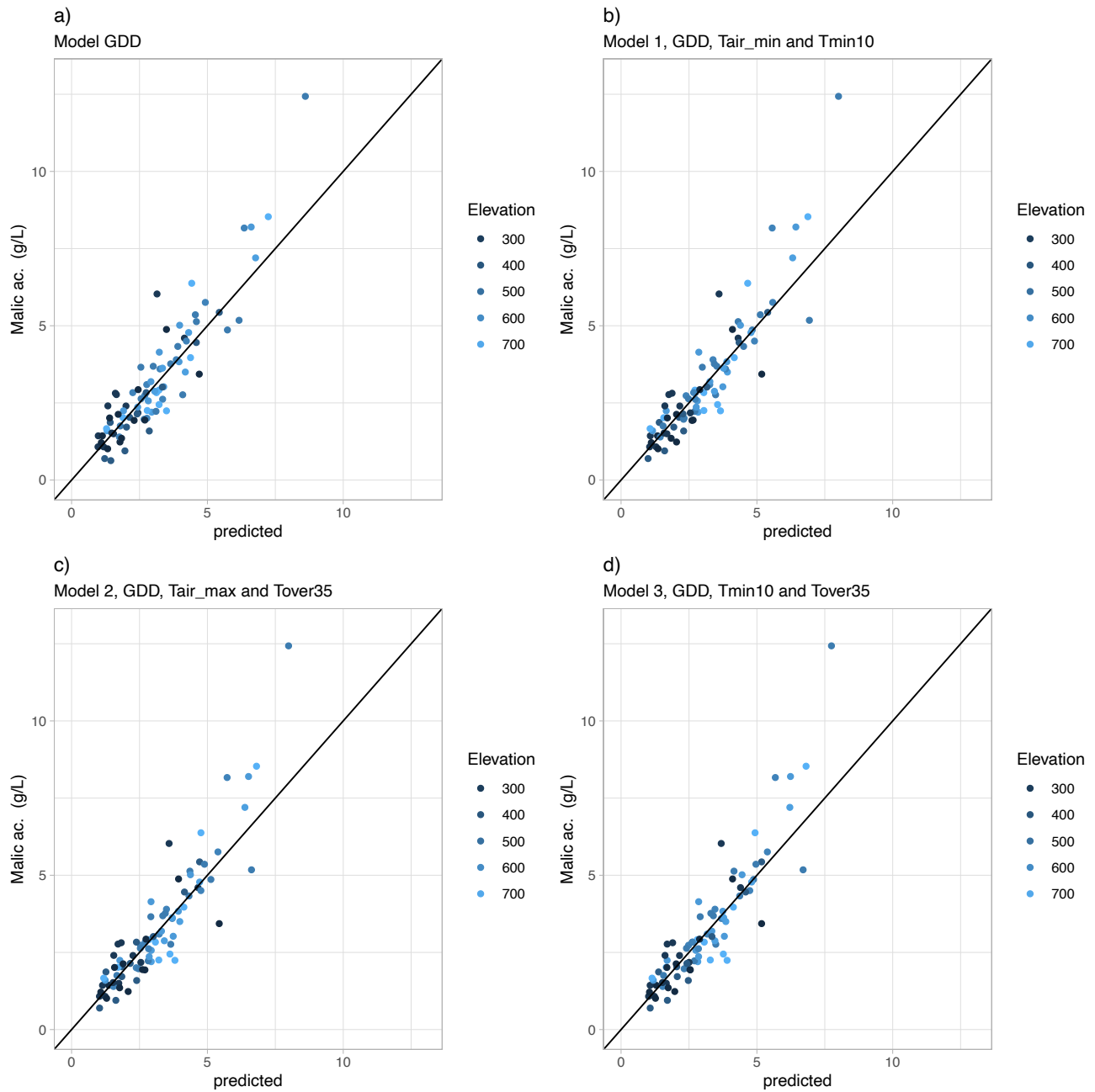


FIGURE S3. Distribution plot of predicted and real vales of the malic acid content by using a) the first proposed model ($MA \sim GDD$) and b), c) and d) the other three improved models.

Points are colored by vineyard elevation and shaped by vintage.

SUPPLEMENTARY DATA

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TABLE S6. Mean of the absolute difference between predicted and real malic acid content, standard deviation, and minimum and maximum values for the models.

	MA ~ GDD	Model.1	Model.2	Model.3
Mean	0.58	0.41	0.42	0.44
Standard deviation	0.77	0.53	0.56	0.58
Min	-1.34	-1.75	-1.74	-2.00
Max	2.84	1.28	1.29	1.22