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Original article

Phenology and production of Hassaoui grapevines as affected by climate anomalies in Al Ahsa region

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ABSTRACT

Climate change is a dramatic crisis that has left severe impacts on viticulture. Phenological events over 41 years and annual climatic anomalies' data over these years in Al Ahsa region were procured. Annual temperature and wind speed anomalies had the strongest influence on all phenological events of the varieties White and Red Hassaoui, starting from the beginning of budburst until harvest. Moreover, the average yield of both varieties decreased significantly by 319.4 and 317 kg ha^{-1} respectively between 1997 and 2019 in comparison with the interval of years 1979–1996. Earlier phenological events were positively correlated with annual temperature anomaly and negatively correlated with annual wind speed anomaly. The latter shortened the dates of occurrence of beginning and full veraison. Yield decreased with higher annual temperature, wind speed and total cloud cover anomalies, and lower annual total precipitation anomaly. Higher annual temperature and wind speed anomalies were correlated with a shorter period between beginning of budburst to beginning of veraison (P3). Shorter periods between beginning and full veraison (P6) and beginning of veraison and harvest (P7) of Red Hassaoui were positively correlated with annual precipitable water anomaly. Results suggest a high level of adaptation of both tested varieties to changing climate conditions in Al Ahsa, though irrigating vines after harvest on a weekly basis would help overcoming the minimal reduction in yield which was caused by the shortage in precipitation.

1. Introduction

Climate change arises after more than ten thousand years of relative stability. The extent of its effects on individual regions will vary over time, with the ability of different social and environmental systems to mitigate or adapt to this issue. Increases in global mean temperature of<1 to 3°Celsius, starting from the year 1990, will produce beneficial impacts in some regions and harmful ones in others (IPCC, 2013). According to Almazroui (2020) the summer maximum temperature is likely to increase continuously for most cities of the Gulf Cooperation Council (GCC) at the rate of about 0.2 °C-0.6 °C per decade for the future period (2020–2099). Earlier studies have also mentioned the possibility of large scale warming over different parts of the Arabian Peninsula as a resultant of the lack of efficient mitigation measures especially in the eastern province of the Kingdom of Saudi Arabia (KSA) and the United Arab Emirates (UAE) (Lelieveld et al., 2016; Pal and Eltahir, 2016). Projections suggest that the rate of increase in agricultural production will slow over the next few decades, and it may start to decline after about 2050 (Verner et al., 2012). Agricultural development

Abbreviations: P3, period between beginning of budburst to beginning of veraison; P6, period between beginning and full veraison; P7, period between beginning of veraison and harvest; GCC, Gulf Cooperation Council; KSA, Kingdom of Saudi Arabia; UAE, United Arab Emirates; ECMWF ERA5, European Centre for Medium-Range Weather Forecasts; Ann PWA, annual precipitable water anomaly; Ann TA, annual temperature anomaly; Ann WSA, annual wind speed anomaly; Ann TPA, annual total precipitation anomaly; Ann TCCA, annual total cloud cover anomaly; stage 1, beginning of budburst; stage 2, full budburst; stage 3, 2–3 leaves unfolded; stage 4, visible inflorescence; stage 5, beginning of flowering; stage 6, full flowering; stage 7, beginning of fruit set; stage 8, full fruit set; stage 9, beginning of veraison; stage 10, full veraison; stage 11, harvest; P1, beginning of budburst to beginning of flowering; P2, beginning of budburst to beginning of fruit set; P3, beginning of budburst to beginning of veraison; P4, beginning of flowering to beginning of veraison; P5, full flowering to full veraison; P6, beginning to full veraison; P7, beginning of veraison to harvest; P8, full veraison to harvest; P9, beginning of flowering to harvest; P10, full flowering to harvest; P11, beginning of budburst to harvest.

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in Arab countries' will be most likely negatively affected by climate change (Tolba and Saab, 2009).

Climate is an important forcing factor on grapevine (*Vitis vinifera* L.) physiological development (Keller, 2010), vegetative growth (Van Leeuwen et al., 2004), phenology (Costa et al., 2019), and production (Jones and Davis, 2000; Fraga and Santos, 2017). The duration of each phenological stage differs according to the cultivated variety, and is generally linked to the thermal conditions of each region (Mandelli et al., 2005). Major drought events occurring in South Africa, were closely related to higher temperature and lower rainfall anomalies, which had negative impacts on grapevines yield (Araujo et al., 2014). Moreover, an increase in temperature especially during springtime will cause an advance in the timing of the phenological events; suggesting high phenological shifts in the long-term (Malheiro et al., 2013). On the other hand, climate change may not necessary affect negatively vineyards yields; for instance, some yield increases are expected in Germany and Hungary (Ponti et al., 2018). It is noteworthy that there is a lack of reports concerning the Gulf countries in the Arabian Peninsula, where a plethora of grape varieties is cultivated for direct consumption or industry (Ghantous et al., 2020; Mohasseb et al., 2020). Many of these varieties showed being directly impacted by climate change (Ghantous et al., 2018). In the Kingdom of Saudi Arabia (KSA), lying between 15.2° and 32.6° North and 34.1° and 55.5° East, the climate is mild during winter, dry, and hot during summer, making it suitable for the cultivation of table grapes; the second most produced fruit in KSA (Fahmi et al., 2012). Between 2001 and 2005, the hectarage of planted fruit crops in KSA increased by 13%, where grapes represented 8.5% of this area, yielding around 132 thousand tons (Al-Qurashi, 2010). Locals reported that Al-Sulaybiya, a region in KSA, supplies more than 20 000 tons of different varieties of grapes all over the country (Al-Harbi, 2016).

Al Ahsa region, located in the east of the Kingdom, is well known for its traditional, original, and high quality white and red grape varieties, known as "Hassaoui". However, the climate change issue may affect this agricultural heritage. No previous studies reported the effect of climate change on grapevine cultivation in the Gulf region, and especially in the KSA. Purposely, the variation of phenological events and production traits of White and Red Hassaoui was assessed in relation to years (over 41 years) and climate anomalies occurring at Al-Ahsa during the same time interval.

2. Materials and methods

2.1. Climatic events

Climate data was sourced from the European Centre for Medium-Range Weather Forecasts (ECMWF ERA5) for the years 1979 until 2019. The climatic annual parameters (precipitable water anomaly (Ann PWA) (kg m^{-2}), temperature anomaly (Ann TA) (°C), wind speed anomaly (Ann WSA) (m s^{-1}), total precipitation anomaly (Ann TPA) (m), total cloud cover anomaly (Ann TCCA) (%) were selected for an adequate interpretation of the climate effect on the different phenological stages of the grapevines.

2.2. Vineyards description

Al Ahsa province is situated in the Eastern part of KSA at an altitude of 100–150 m above sea level, where summers are long, sweltering, and arid, winters are cool and dry, and it is mostly clear year round. Sunlight lasts in average between 10.3 h to 13.4 h, with a mean fall in temperature of around 10–15 °C between day and night. The vineyards under study were cultivated by White and Red Hassaoui covering a surface of 20,200 and 23100 m^2, respectively. In both vineyards, the distance of plantation was of 2.5 m × 1.25 m. White and Red Hassaoui vines were pruned back to spurs about a hand's width apart, each with two buds. Both vineyards applied a two-line drip irrigation system with three drippers providing 6 L of water per hour per vine. Vines were irrigated once every two weeks. The analysis of physico-chemical characteristics of soil at the selected vineyards is provided in Table 1.

2.3. Data collection

Data on vines (phenological events and yield) was procured by local agricultural engineers, and consisted on yearly records taken on productive vineyards of White or Red Hassaoui in Al Ahsa. At the selected vineyards, vines were randomly selected from the sides and the centre rows for data collection. Assessment of vine's phenology covered; the beginning of budburst (stage 1), full budburst (stage 2), 2–3 leaves unfolded (stage 3), visible inflorescence (stage 4), beginning of flowering (stage 5), full flowering (stage 6), beginning of fruit set (stage 7), full fruit set (stage 8), beginning of veraison (stage 9), full veraison (stage 10), and harvest (stage 11).

The stages 1, 3, 4, 5, 7, and 9 were recorded once 10% of the total number of selected vines reached the relative stage, while the stages 6, 8, 10, and 11 were determined when 80% of selected plants reached the relative stage. The stage 2 was recorded when green shoot tips were visible on all sampled vines. All stages were expressed in days after leaf fall, considering the leaf fall stage as the reference day to evaluate the evolution in phenological events.

In addition, the periods (in days) between the different phenological stages were determined as follows: beginning of budburst to beginning of flowering (P1), beginning of budburst to beginning of fruit set (P2), beginning of budburst to beginning of veraison (P3), beginning of flowering to beginning of veraison (P4), full flowering to full veraison (P5), beginning to full veraison (P6), beginning of veraison to harvest (P7), full veraison to harvest (P8), beginning of flowering to harvest (P9), full flowering to harvest (P10), and beginning of budburst to harvest (P11). The production of grapevines was evaluated in terms of yield (recorded per vine and then expressed as kg ha^{-1}).

2.4. Statistical analysis

Pearson's correlations were applied to detect the relation between the assessed indicators (occurrence of phenological events, periods between phenological events, and yield) and climate anomalies. Cluster analysis was performed using SPSS program in order to divide years (from 1979 to 2019) based on climate anomalies; each cluster included a series of years having comparable means of the already listed climate factors anomalies. The contribution of each climate anomaly in the cluster analysis

Table 1
Physico-chemical composition of soil at the experimental vineyards.

Parameter	White Hassaoui vineyards	Red Hassaoui vineyards
Sandy (%)	89.2	89.6
Silt (%)	5.8	5.6
Clay (%)	5.0	4.8
pH	7.7	7.6
EC (dS/m)	1.5	1.8
Cations (mEq/L)		
Na^+	10.9	10.8
K^+	0.32	0.28
Ca^{2+}	2.9	3.2
Mg^{2+}	2.72	2.76
Anions (mEq/L)		
Cl^-	8.8	9.2
HCO_3^-	3.4	3.0
SO_4^{2-}	4.5	4.3

was determined using the factor analysis option provided by SPSS program. Besides, Duncan test compared the means of vines' indicators in between years. P_{value} < 0.05 and < 0.01 were adopted in all statistical tests.

3. Results

3.1. Variation of climatic anomalies

Assessment of climate anomalies from 1979 until 2019 (Fig. 1) shows there were consecutive fluctuations in Ann TCCA over the presented years between positive and negative values. The highest positive value of Ann TCCA, recorded in 2006 (7.98%), indicating that observed total cloud cover was the most dense compared to the normal baseline, while the lowest Ann TCCA, in 1999 (-5.06%), indicating that observed total cloud cover was the least dense compared to the normal baseline in the region.

Similarly, Ann PWA (Fig. 2) fluctuated between positive and negative values. The highest positive value of Ann PWA, recorded in 2019 (2.98 kg m^{-2}), indicated that evaporated water was the most condensate compared to the normal baseline, while the lowest Ann PWA, in 1989 (-1.40 kg m^{-2}), indicated that precipitable water was the least condensate compared to the normal baseline in Al Ahsa region.

Ann TA (Fig. 3) followed a continuous positive pattern since 1997 until 2019. Ann TA was also positive during the years 1980, 1981, 1983, 1987, 1988, 1990, 1991, 1995. The highest shift upwards of temperature at Al Ahsa was in 2016 (where Ann TA reached 0.74 °C), while the highest shift downwards was in 1993 (where Ann TA reached −0.21 °C).

Except in 2015 and 2019, annual total precipitation (Fig. 4) deviated from the normal annual baseline, whether positively or negatively. During several years, recorded total precipitation was higher than the normal, but during others, it was abnormally low in Al Ahsa. The strongest shift downwards of total precipitation were in 1981, 1994, 2001, and 2010.

Abnormal values of annual wind speed (Fig. 5) were positive during 23 years out of 41 years under investigation, and negative during the remaining years. The highest upwards shift of annual wind speed was in 1984 (Ann WSA = 0.34 m s^{-1}), followed by 2008, 1996, and 2013 (Ann WSA = 0.17, 0.16, and 0.15 m s^{-1} respectively). The highest downwards shift of this climate factor was in 1996 (Ann WSA = -0.25 m s^{-1}), followed by 2017 and 2010 (Ann WSA = -0.21 and −0.15 m s^{-1}, respectively).

3.2. Pearson's correlations

Pearson' correlations (Table 2) showed that the phenological stages starting from beginning of budburst till full fruit set (stages 1 to 8) and harvest (stage 11) of the White Hassaoui were positively correlated with Ann TA (at a 99% confidence level) and negatively correlated with Ann WSA (at a 95% confidence level). Stages 9 and 10 were positively correlated with Ann TA and Ann WSA (at 99% and 95% confidence levels, respectively). Stages 5 and 11 were strongly positively correlated with Ann PWA (at 95% and 99% confidence, levels respectively). Yield was negatively correlated with Ann TCCA, Ann TA and Ann WSA, and positively with Ann TPA (at a 99% confidence level). The period from beginning of budburst and beginning of veraison (P3) was positively correlated with Ann TA and Ann WSA (at 99% and 95% confidence levels, respectively).

In a similar pattern to the White Hassaoui, the stages 1 to 8 (from beginning of budburst till full fruit set) and the stage 11 (harvest) of the Red Hassaoui (Table 3) were positively correlated with Ann TA (at a 99% confidence level), and negatively with Ann WSA (at a 95% confidence level). The stages of beginning and full veraison (stages 9 and 10) were positively correlated with Ann PWA and Ann WSA at a 95% confidence level, and with Ann TA (at a 99% confidence level). Beginning and full flowering (stages 7 and 8) and the period from beginning of budburst to beginning of fruit set (P2) were negatively correlated with Ann TCCA (at a 95% confidence level). Yield was negatively correlated with Ann TCCA, Ann TA, and Ann WSA, and positively with Ann TPA (at a 99% confidence level). The period from beginning of budburst to beginning of veraison (P3) was positively correlated with Ann TA and Ann WSA (at 99% and 95% levels of confidence, respectively). The periods from beginning to full veraison (P6) and from beginning of veraison to harvest (P7) were positively correlated with Ann PWA (at a 95% confidence level).

3.3. Cluster analysis

The two-step cluster analysis (Table 4) showed two identifiable year clusters based on the climate anomalies which occurred all over 41 years. The first cluster grouped the years between 1979 and 1996 (both included), while the second cluster grouped the remaining years from 1997 till 2019 (both included) showing a clear climate change in Al Ahsa region in the last two decades.

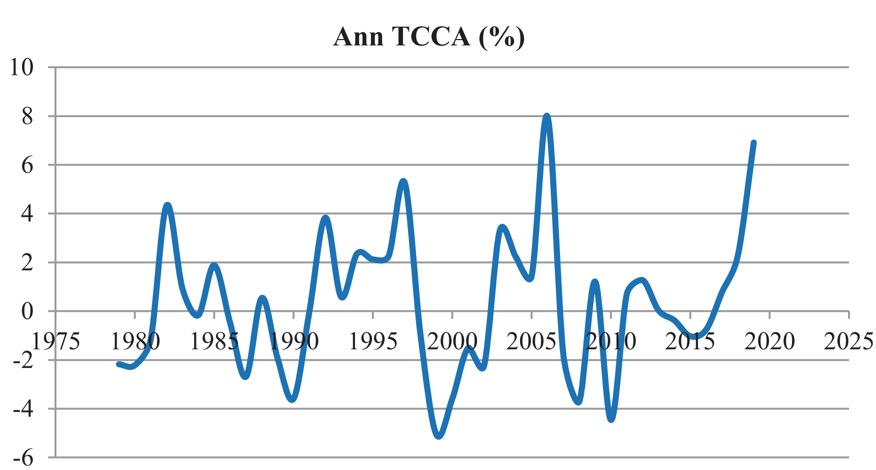

Fig. 1. Annual total cloud cover anomaly (Ann TCCA) over 41 years at Al Ahsa, KSA.

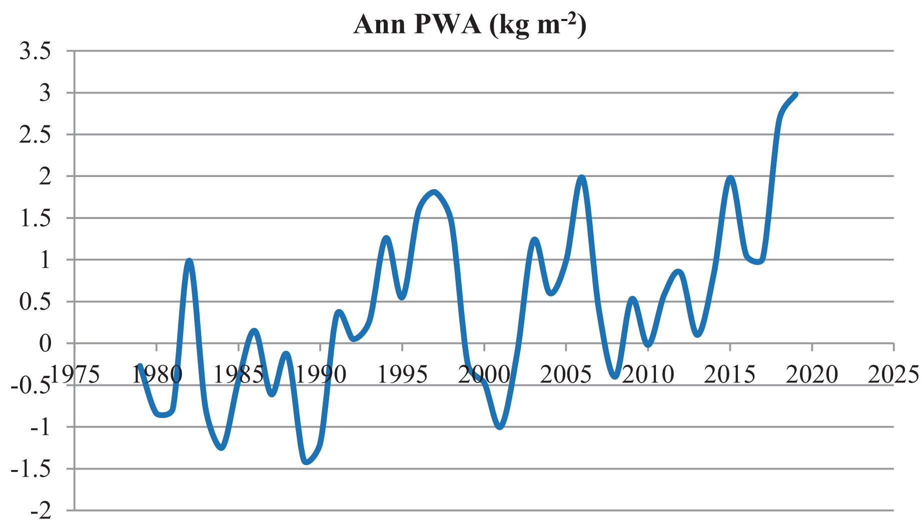

Fig. 2. Annual precipitable water anomaly (Ann PWA) over 41 years at Al Ahsa, KSA.

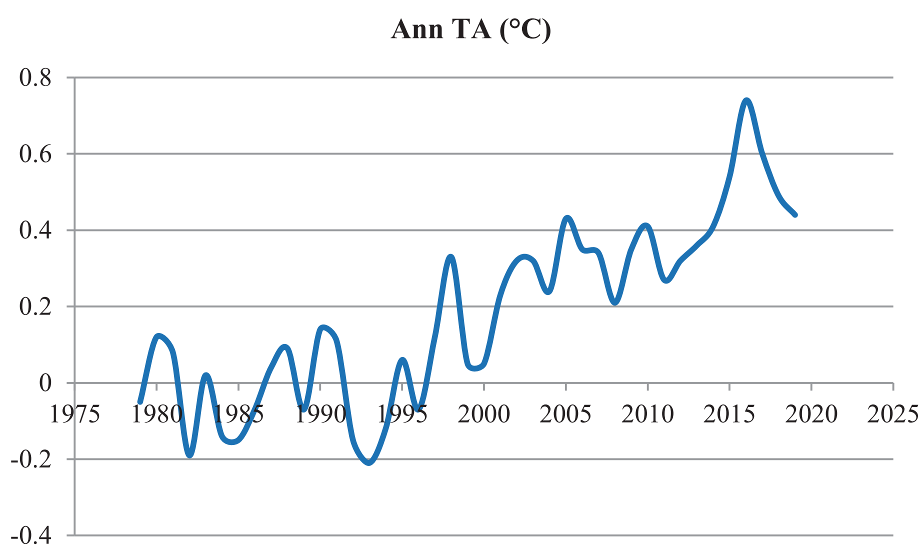

Fig. 3. Annual temperature anomaly (Ann TA) over 41 years at Al Ahsa, KSA.

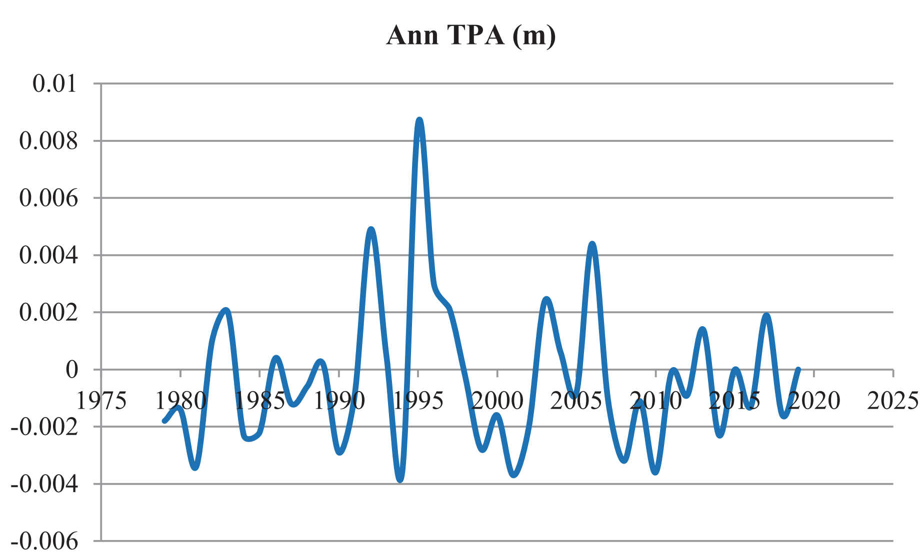

Fig. 4. Annual total precipitations (Ann TPA) anomaly over 41 years at Al Ahsa, KSA.

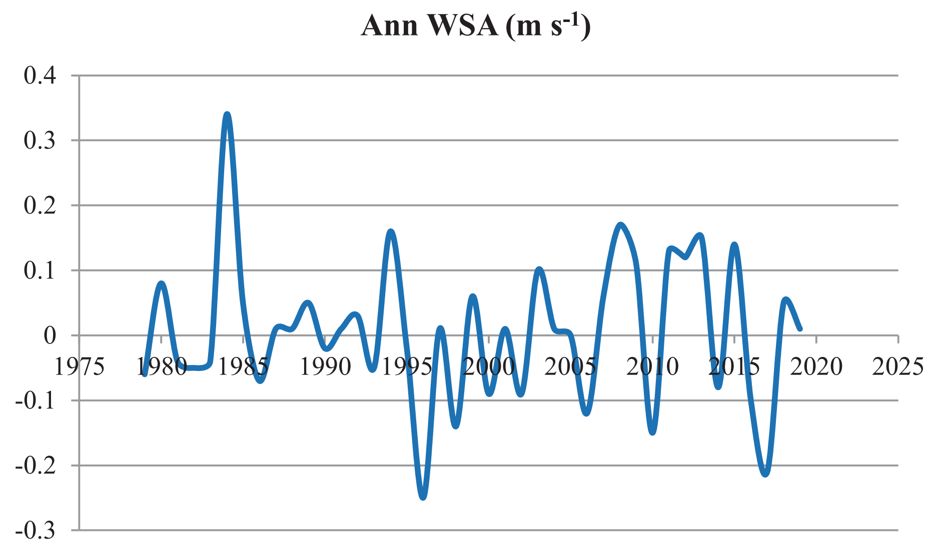

Fig. 5. Annual wind speed anomaly (Ann WSA) over 41 years at Al Ahsa, KSA.

Table 2
Pearson's correlations between phenological stages, periods between them, and yield in White Hassaoui vineyard (vineyard 1).

	Ann TCCA	Ann PWA	Ann TA	Ann TPA	Ann WSA
Stage 1	−0.318	0.245	0.941**	−0.130	−0.830*
Stage 2	−0.349	0.358	0.936**	−0.135	−0.752*
	−0.472	0.234	0.977**	−0.143	−0.736*
Stage 4	−0.258	0.369	0.965**	−0.038	−0.783*
Stage 5	−0.421	0.768*	0.989**	−0.155	−0.772*
Stage 6	−0.237	0.511	0.902**	−0.241	−0.802*
Stage 7	−0.521	0.394	0.973**	−0.254	−0.813*
Stage 8	−0.413	0.542	0.944**	−0.281	−0.768*
Stage 9	−0.336	0.549	0.924**	−0.156	0.723*
Stage 10	−0.446	0.311	0.989**	−0.152	0.739*
Stage 11	−0.350	0.941**	0.910**	−0.120	−0.725*
Yield	−0.917**	−0.258	−0.978**	0.952**	−0.964**
P1	−0.228	0.314	0.428	−0.110	0.012
P2	−0.312	0.272	0.371	−0.230	0.105
P3	−0.233	0.397	0.922**	−0.155	0.811*
P4	−0.207	0.373	0.387	−0.138	0.107
P5	−0.429	0.129	0.473	−0.206	0.178
P6	−0.117	0.134	0.238	−0.048	0.222
P7	−0.178	0.147	0.173	−0.027	0.156
P8	−0.164	0.234	0.290	−0.119	0.262
P9	−0.125	0.098	0.393	−0.226	0.388
P10	−0.195	0.165	0.189	−0.124	0.094
P11	−0.274	0.138	0.274	−0.078	0.268

Stage 1: beginning of budburst, stage 2: full budburst, stage 3: 2–3 leaves unfolded, stage 4: visible inflorescence, stage 5: beginning of flowering, stage 6: full flowering, stage 7: beginning fruit set, stage 8: full fruit set, stage 9: beginning of veraison, stage 10: full veraison, stage 11: harvest, P1: beginning of budburst to beginning of flowering, P2: beginning of budburst to beginning of fruit set, P3: beginning of budburst to beginning of veraison, P4: beginning of flowering to beginning of veraison, P5: full flowering to full veraison, P6: beginning to full veraison, P7: beginning of veraison to harvest, P8: full veraison to harvest, P9: beginning of flowering to harvest, P10: full flowering to harvest, P11: beginning of budburst to harvest, Ann TCCA: annual total cloud cover anomaly, Ann PWA: annual precipitable water anomaly, Ann TA: annual temperature anomaly, Ann TPA: annual total precipitation anomaly, Ann WSA: annual wind speed anomaly. *: Correlation is significant at the 0.05 level, **: Correlation is significant at the 0.01 level.

Table 3
Pearson's correlations between phenological events, periods between them and yield in Red Hassaoui vineyard (vineyard 2).

	Ann TCCA	Ann PWA	Ann TA	Ann TPA	Ann WSA
Stage 1	−0.421	0.233	0.933**	−0.107	−0.726*
Stage 2	−0.268	0.317	0.942**	−0.165	−0.779*
Stage 3	−0.178	0.215	0.958**	−0.131	−0.725*
Stage 4	−0.369	0.337	0.981**	−0.087	−0.812*
Stage 5	−0.246	0.617	0.978**	−0.213	−0.741*
Stage 6	−0.227	0.478	0.913**	−0.222	−0.748*
Stage 7	−0.720*	0.316	0.947**	−0.238	−0.800*
Stage 8	−0.736*	0.422	0.931**	−0.273	−0.739*
Stage 9	−0.249	0.749*	0.920**	−0.148	0.710*
Stage 10	−0.342	0.711*	0.968**	−0.161	0.802*
Stage 11	−0.228	0.423	0.940**	−0.108	−0.719*
Yield	−0.943**	−0.320	−0.929**	0.914**	−0.971**
P1	−0.217	0.373	0.472	−0.102	0.103
P2	−0.712*	0.221	0.529	−0.314	0.063
P3	−0.147	0.661	0.945**	−0.196	0.755*
P4	−0.308	0.682	0.415	−0.143	0.114
P5	−0.317	0.511	0.512	−0.218	0.136
P6	−0.284	0.714*	0.361	−0.072	0.249
P7	−0.105	0.735*	0.579	−0.039	0.123
P8	−0.131	0.324	0.404	−0.114	0.240
P9	−0.189	0.389	0.525	−0.254	0.395
P10	−0.283	0.527	0.437	−0.201	0.111
P11	−0.319	0.188	0.674	−0.062	0.315

Stage 1: beginning of budburst, stage 2: full budburst, stage 3: 2–3 leaves unfolded, stage 4: visible inflorescence, stage 5: beginning of flowering, stage 6: full flowering, stage 7: beginning fruit set, stage 8: full fruit set, stage 9: beginning of veraison, stage 10: full veraison, stage 11: harvest, P1: beginning of budburst to beginning of flowering, P2: beginning of budburst to beginning of fruit set, P3: beginning of budburst to beginning of veraison, P4: beginning of flowering to beginning of veraison, P5: full flowering to full veraison, P6: beginning to full veraison, P7: beginning of veraison to harvest, P8: full veraison to harvest, P9: beginning of flowering to harvest, P10: full flowering to harvest, P11: beginning of budburst to harvest, Ann TCCA: annual total cloud cover anomaly, Ann PWA: annual precipitable water anomaly, Ann TA: annual temperature anomaly, Ann TPA: annual total precipitation anomaly, Ann WSA: annual wind speed anomaly. *: Correlation is significant at the 0.05 level, **: Correlation is significant at the 0.01 level

3.4. Factor strength and contribution

The factor analysis (Table 5) showed that annual total cloud cover anomaly (Ann TCCA) first, and annual precipitable water anomaly (Ann PWA) secondly were the main and most influencing predictors, followed by annual temperature anomaly (Ann TA).

3.5. Vine phenology

Results in Table 6 showed that in cluster 2 years (from 1997 till 2019), the phenological stages: beginning of budburst (stage 1), full budburst (stage 2), 2–3 leaves unfolded (stage 3), and visible inflorescence (stage 4) of White Hassaoui were hastened by around 19 days in comparison with the mean values of cluster 1 years

Table 4
Cluster analysis based on the climate anomalies.

Cluster 1	Cluster 2
1979	1997
1980	1998
1981	1999
1982	2000
1983	2001
1984	2002
1985	2003
1986	2004
1987	2005
1988	2006
1989	2007
1990	2008
1991	2009
1992	2010
1993	2011
1994	2012
1995	2013
1996	2013
	2014
	2015
	2016
	2017
	2018
	2019

Table 5
Contribution level of each predictor.

Predictor	Importance
Ann TCCA (%)	2.13
Ann PWA (kg m^{-2})	1.27
Ann TA (°C)	1.01
Ann WSA (m s^{-1})	0.43
Ann TPA (m)	0.16

Ann TCCA: annual total cloud cover anomaly, Ann PWA: annual precipitable water anomaly, Ann TA: annual temperature anomaly, Ann WSA: annual wind speed anomaly, Ann TPA: annual total precipitation anomaly.

Table 6
Variation of stages 1 to 4 phenological events of White Hassaoui as affected by year.

Year	Stage 1 (Days)	Stage 2 (Days)	Stage 3 (Days)	Stage 4 (Days)
1979	210r	213p	215 s	227r
1980	202mn	206 *m*	209op	219mn
1981	203no	206 *m*	208no	220no
1982	217u	221u	224v	234u
1983	206q	211o	213r	223q
1984	214st	218 s	221u	231st
1985	215 t	218 s	220u	232 t
1986	211r	215r	218 t	228r
1987	205pq	208*n*	211q	222pq
1988	203no	208*n*	210pq	220no
1989	211r	213p	216 s	228r
1990	200 l	204 l	207*n*	217 l
1991	202mn	205 lm	208no	219mn
1992	215 t	219st	221u	232 t
1993	218u	220tu	223v	235u
1994	213 s	216r	218 t	230 s
1995	204op	208*n*	211q	221op
1996	211r	213p	216 s	228r
Cluster 1	208.9B	212.3B	214.9B	225.9B
1997	201 lm	205 lm	207*n*	218 lm
1998	191 h	194gh	196ij	208 h
1999	205pq	209*n*	211q	222pq
2000	205pq	208*n*	210pq	222pq
2001	196jk	200jk	203 lm	213jk
2002	191 h	194gh	196ij	208 h
2003	191 h	194gh	196ij	208 h
2004	195ij	199j	202 l	212ij
2005	186ef	188e	191e	203ef
2006	190gh	193 g	195hi	207gh
2007	190gh	193 g	195hi	207gh
2008	197 k	201 k	204 *m*	214 k
2009	190gh	194gh	197j	207gh
2010	187f	189e	192ef	204f
2011	194i	197i	199 k	211i
2012	191 h	195 h	197j	208 h
2013	189 g	191f	194gh	206 g
2014	187f	191f	193 fg	204f
2015	180c	183c	185c	197c
2016	170a	172a	175a	187a
2017	177b	179b	182b	194b
2018	183d	186d	188d	200d
2019	185e	189e	191e	202e
Cluster 2	190.0 A	193.2 A	195.6 A	207.0 A

Stage 1: beginning of budburst, stage 2: full budburst, stage 3: 2–3 leaves unfolded, stage 4: visible inflorescence. Means within the same row followed by the same letters are not significantly different at $P < 0.05$ according to Duncan's multiple range test.

(from 1979 till 1996). Also, the phenological stages: beginning of flowering (stage 5), full flowering (stage 6), beginning of fruit set (stage 7) and full fruit set (stage 8) were hastened by around 18 days from 1997 and 2019 in comparison with the mean values of cluster 1 years (Table 7). Moreover, the phenological stages: beginning veraison (stage 9), full veraison (stage 10) and harvest (stage 11) in cluster 2 years were hastened by around 17, 19, and 19 days, respectively compared to their mean values in the first cluster of years (Table 8). All phenological events were the earliest in the last five years (2015–2019), especially in 2016. The average yield of White Hassaoui varied greatly between the two clusters of years, recording the lowest value in 2001 (11277.6 kg ha^{-1}) and the highest one in 1995 (18867.4 kg ha^{-1}). Average yield was higher by 319.4 kg ha^{-1} in cluster 1 years (1979 to 1996) compared to cluster 2 (1997 to 2019) (Table 8).

Concerning the Red Hassaoui, results in Tables 9 and 10 showed that during the cluster 2 years (from 1997 till 2019), the phenological stages 1 (beginning of budburst), 2 (full budburst), 3 (2–3 leaves unfolded), 4 (visible inflorescence), 5 (beginning of flowering), 6 (full flowering), 7 (beginning of fruit set), and 8 (full fruit set) were reduced by around 22, 22, 21, 21, 21, 22, 22, and 22 days respectively compared to the mean values of same indicators recorded in the cluster 1 years (from 1979 till 1996). Also, the beginning of veraison (stage 9), full veraison (stage 10), and harvest (stage 11) were earlier by around 22 days in years of cluster 2 compared to cluster 1 (Table 11). Phenological events of Red Hassaoui also were the earliest in the years 2015 till 2019), especially in 2016. Average yield of this variety recorded the lowest values in 2001 (11126.17 kg ha^{-1}) and 2010 (11154.28 kg ha^{-1}), and the highest value in 1995 (18426.84 kg ha^{-1}). In average, yield decreased by 317 kg ha^{-1} between 1997 and 2019, compared with its average value noted between 1979 and 1996 (Table 11).

4. Discussion

Weather and climate factors are the keys that govern viticulture (Keller, 2010). Effectively, air temperature may be the biggest factor that influences vines' vegetative cycle. Precipitation and radiation are also important, though to a lesser extent (Malheiro et al., 2013). In general, higher temperatures during the latter part of winter will accelerate budburst date, and stimulate the vegetative growth during the growing season (Pearce and Coombe. 2004; Keller and Tarara, 2010); a cumulative effect of temperatures above a threshold of 10 °C being the classical thermal requirement for budburst occurrence (Winkler et al., 1974). In the current study, an increasing annual temperature anomaly occurring in Al Ahsa

Table 7
Variation of stages 5 to 8 phenological events of White Hassaoui as affected by year.

Year	Stage 5 (Days)	Stage 6 (Days)	Stage 7 (Days)	Stage 8 (Days)
1979	236 l	241r	241r	258p
1980	227j	233mn	233mn	248 l
1981	230 k	234no	234no	250mn
1982	243o	248u	248u	263r
1983	231 k	237q	237q	254o
1984	240*n*	245st	245st	261q
1985	240*n*	246 t	246 t	261q
1986	238 *m*	242r	242r	258p
1987	231 k	236pq	236pq	253o
1988	230 k	234no	234no	250mn
1989	236 l	242r	242r	257p
1990	227j	231 l	231 l	248 l
1991	228j	233mn	233mn	249 lm
1992	240*n*	246 t	246 t	261q
1993	244o	249u	249u	265 s
1994	238 *m*	244 s	244 s	260q
1995	231 k	235op	235op	251*n*
1996	236 l	242r	242r	257p
Cluster 1	234.8B	240.0B	240.0B	256.0B
1997	228j	232 lm	232 lm	248 l
1998	218 g	222 h	222 h	239 h
1999	231 k	236pq	236pq	253o
2000	231 k	236pq	236pq	253o
2001	223i	227jk	227jk	244jk
2002	218 g	222 h	222 h	239 h
2003	218 g	222 h	222 h	239 h
2004	222i	226ij	226ij	243ij
2005	213e	217ef	217ef	234ef
2006	216f	221gh	221gh	238gh
2007	216f	221gh	221gh	238gh
2008	222i	228 k	228 k	245 k
2009	217 fg	221gh	221gh	238gh
2010	214e	218f	218f	235f
2011	220 h	225i	225i	242i
2012	218 g	222 h	222 h	239 h
2013	216f	220 g	220 g	237 g
2014	213e	218f	218f	235f
2015	207c	211c	211c	228c
2016	196a	201a	201a	218a
2017	204b	208b	208b	225b
2018	209d	214d	214d	231d
2019	210d	216e	216e	233e
Cluster 2	216.5 A	221.0 A	221.0 A	238.0 A

Stage 5: beginning of flowering, stage 6: full flowering, stage 7: beginning fruit set, stage 8: full fruit set. Means within the same row followed by the same letters are not significantly different at $P < 0.05$ according to Duncan's multiple range test.

Table 8
Variation of stages 9 to 11 phenological events and yield of White Hassaoui as affected by year.

Year	Stage 9 (Days)	Stage 10 (Days)	Stage 11 (Days)	Yield (kg ha^{-1})
1979	294qr	308pq	323*n*	12329.5de
1980	286mn	300mn	314 l	13522.3f
1981	285 lm	301mn	317 *m*	11410.4abc
1982	297 t	315 t	330p	15347.2mn
1983	290o	304o	318 *m*	15921.3o
1984	295rs	312rs	328o	11858.5bcd
1985	296st	313st	328o	11921.7bcd
1986	295rs	309pq	323*n*	14852.2klm
1987	289o	303o	318 *m*	13736.8 fg
1988	286mn	301mn	314 l	14127.5ghij
1989	292p	309pq	324*n*	14624.4jkl
1990	284 l	298 l	314 l	11656.0abc
1991	286mn	301mn	315 l	13934.4fghi
1992	295rs	313st	328o	17150.8q
1993	300u	316u	330p	14987.2 lm
1994	296st	311rs	324*n*	11355.8ab
1995	287*n*	302*n*	317 *m*	18867.4r
1996	293pq	309pq	324*n*	16474.6p
Cluster 1	291.0B	307.0B	321.6B	14115.4B
1997	284 l	299 l	314 l	15987.3op
1998	275 h	289 h	304 h	14366.5hijk
1999	289o	303o	317 *m*	11687.9abc
2000	289o	303o	317 *m*	12531.2e
2001	280jk	294jk	309jk	11277.6a
2002	275 h	289 h	304 h	11965.2 cd
2003	275 h	289 h	304 h	16038.9op
2004	279ij	293ij	308ij	15064.7 lm
2005	270ef	284ef	299ef	13983.4fghi
2006	274gh	288gh	303gh	17026.5q
2007	274gh	288gh	303gh	13842.7fgh
2008	281 k	295 k	310 k	11568.7abc
2009	274gh	288gh	303gh	13844.2fgh
2010	271f	285f	300f	11357.3ab
2011	278i	292i	307i	14425.0ijk
2012	275 h	289 h	304 h	13956.5fghi
2013	273 g	287 g	302 g	15622.4no
2014	271f	285f	300f	11879bcd
2015	264c	278c	293c	14399.5hijk
2016	254a	268a	283a	13684.1 fg
2017	261b	275b	290b	15889.4o
2018	267d	281d	296d	12537.7e
2019	269e	283e	298e	14405.9hijk
Cluster 2	274.0 A	288.0 A	303.0 A	13796.0 A

Stage 9: beginning of veraison, stage 10: full veraison, stage 11: harvest. Means within the same row followed by the same letters are not significantly different at $P < 0.05$ according to Duncan's multiple range test.

region was correlated with an earliness in budburst and the majority of phenological events. It was mainly observed in 2016 where the highest upward shift in temperature occurred, reflecting abnormally high air temperature in Al Ahsa. Most studies that addressed the links between climate change and vine phenology have reported earlier occurrence of phenological events, shorter phenological intervals, and warmer grape maturation periods, correlating these changes to the rise in temperature (Bock et al., 2011; Tomasi et al., 2011; Urhausen et al., 2011; Malheiro et al., 2013). Keller (2010), Webb et al. (2012), and Jones (2013) have more specifically reported that higher temperatures will reduce the days to beginning of flowering, veraison, and harvest, confirming our results. Annual temperature anomaly has effectively affected the interval between budburst and veraison of both varieties. In fact, annual temperature anomaly resulted in a hastened harvest of Hassaoui grapes by 19–22 days since 1997 in comparison with earlier years. Roselli et al. (2020) mentioned that early harvest of table grapes in Italy was of high economic returns. Jones and Davis (2000) reported that the shortening of the intervals between flowering to veraison and veraison to harvest is generally linked to better climatic conditions for growth and development. Moreover, the study conducted by Koch and Oehl (2018) in south-west Germany revealed an average 10–24-day shifts in the onset of most important grape phenological events from 1975 until 2015 as a result of the increasing heat stress. Due to the climate change occurring worldwide and affecting naturally the Gulf region in general and KSA in specific, the annual total precipitation were abnormally low in the period after 1997, with some few exceptions, assumedly causing reduction in yield of White and Red Hassaoui. Water stress during budburst and inflorescence development leads to poor flower-clustering development and berry set (Hardie and Considine, 1976), because high soil moisture during this stage is a must for the grapevine growth (Hardie and Martin, 2000). Further, low rainfall impact yield by reducing berry weight and size (Attia, 2007). Changes in grapevine water status at critical phenological stages have a direct effect on grape composition and quality attributes by affecting vegetative growth, yield, and fruit metabolism (Ezzhaouani et al., 2007). Studied vines in the currently presented vineyards were only irrigated from bloom to fruit set. However, irrigating vines after harvest once weekly until June would overcome the water lack caused by reduced precipitations.

Table 9
Variation of stages 1 to 4 phenological events of Red Hassaoui as affected by year.

Year	Stage 1 (Days)	Stage 2 (Days)	Stage 3 (Days)	Stage 4 (Days)
1979	215 s	218 t	220rs	232r
1980	206p	210q	213op	226o
1981	204o	209pq	213op	224*n*
1982	218 t	222wx	224u	235 s
1983	207p	210q	214p	225no
1984	215 s	220uv	222 t	234 s
1985	216 s	221vw	224u	235 s
1986	212qr	215rs	219r	231qr
1987	206p	210q	214p	226o
1988	203no	207o	210*n*	222 *m*
1989	211q	214r	216q	228p
1990	200 l	205*n*	208 *m*	221 lm
1991	202mn	205*n*	209mn	221 lm
1992	215 s	219tu	221st	232r
1993	218 t	223x	226v	237 t
1994	213r	216 s	220rs	232r
1995	204o	208op	210*n*	221 lm
1996	211q	216 s	219r	230q
Cluster 1	210.0B	214.0B	216.8B	228.4B
1997	201 lm	205*n*	209mn	220 l
1998	190i	193ij	197ij	209ij
1999	204o	209pq	212o	224*n*
2000	204o	207o	209mn	221 lm
2001	195 k	199 *m*	201 l	212 k
2002	190i	195 k	198jk	210j
2003	190i	194jk	197ij	209ij
2004	194 k	197 l	201 l	212 k
2005	184ef	189f	192f	203e
2006	188gh	192hi	196hi	207gh
2007	188gh	191gh	195gh	206 fg
2008	195 k	198 lm	202 l	213 k
2009	188gh	192hi	196hi	207gh
2010	185f	190 fg	194 g	205f
2011	192j	195 k	199 k	210j
2012	189hi	193ij	197ij	208hi
2013	187 g	192hi	196hi	208hi
2014	184ef	187e	191ef	203e
2015	177c	181c	185c	196c
2016	167a	172a	176a	188a
2017	174b	178b	182b	193b
2018	180d	184d	188d	200d
2019	183e	186e	190e	202e
Cluster 2	188.2 A	192.1 A	195.8 A	207.2 A

Stage 1: beginning of budburst, stage 2: full budburst, stage 3: 2–3 leaves unfolded, stage 4: visible inflorescence. Means within the same row followed by the same letters are not significantly different at $P < 0.05$ according to Duncan's multiple range test.

Table 10
Variation of stages 5 to 8 phenological events of Red Hassaoui as affected by year.

Year	Stage 5 (Days)	Stage 6 (Days)	Stage 7 (Days)	Stage 8 (Days)
1979	241q	246rs	246rs	263 s
1980	236p	242p	242p	258q
1981	232mn	238no	238no	253o
1982	244r	248 t	248 t	265tu
1983	233no	238no	238no	255p
1984	244r	248 t	248 t	263 s
1985	243r	247st	247st	264st
1986	240q	245qr	245qr	261r
1987	236p	242p	242p	258q
1988	230kl	234 lm	234 lm	251mn
1989	237p	242p	242p	259q
1990	231 lm	237*n*	237*n*	253o
1991	229jk	233kl	233kl	250 lm
1992	241q	246rs	246rs	263 s
1993	247 s	251u	251u	266u
1994	240q	244q	244q	261r
1995	230kl	235 *m*	235 *m*	252no
1996	240q	244q	244q	259q
Cluster 1	237.0B	242.0B	242.0B	258.6B
1997	228j	232 k	232 k	249 l
1998	218 h	223i	223i	238i
1999	234o	239o	239o	255p
2000	230kl	235 *m*	235 *m*	252no
2001	221i	226j	226j	243 k
2002	218 h	222hi	222hi	238i
2003	217gh	221gh	221gh	238i
2004	220i	225j	225j	242 k
2005	211e	215e	215e	232e
2006	216 fg	220 fg	220 fg	236gh
2007	216 fg	221gh	221gh	236gh
2008	221i	226j	226j	243 k
2009	216 fg	220 fg	220 fg	236gh
2010	215f	219f	219f	234f
2011	218 h	223i	223i	240j
2012	217gh	221gh	221gh	237hi
2013	216 fg	220 fg	220 fg	235 fg
2014	212e	216e	216e	232e
2015	206c	210c	210c	225c
2016	196a	200a	200a	215a
2017	202b	207b	207b	222b
2018	208d	212d	212d	228d
2019	211e	215e	215e	231e
Cluster 2	216.0 A	220.3 A	220.3 A	236.4 A

Stage 5: beginning of flowering, stage 6: full flowering, stage 7: beginning fruit set, stage 8: full fruit set. Means within the same row followed by the same letters are not significantly different at $P < 0.05$ according to Duncan's multiple range test.

Earlier, Ghantous et al. (2020) adopted this method of irrigation on Malbec grapevines after harvest until June and acknowledged higher yields. This suggests that farmers have wrongly estimated the heaviness of drought anomaly and the irrigation's timing wasn't helpful. contradict this statement. The increase in annual total cloud cover anomaly was negatively correlated with yields of White and Red Hassaoui grapevines, which suggests that lower solar radiation may have negatively affected fruit set. Earlier, Ebadi (1996) reported that cloudy weather during flowering leads to poor fruit set as affected by reduced photosynthesis and thereby, lower light incidence. Jones and Davies (2000) noted that during flowering, veraison, and harvest warm temperatures are required for balanced crop yield. Abnormal temperature increase for consecutive 23 years (between 1997 till 2019) (ranging between a minimum of + 0.12 °C in 1997 and a maximum of + 0.74 °C in 2016) caused a minimal yield reduction by 2.6% and 2.2% for White and Red Hassaoui, respectively compared to earliest years (before 1979). Fidelibus (2018) detected that spring heat waves can reduce fruit set, and thus decrease yield. On the contrary, Greer and Weedon (2013) have earlier found that high temperatures didn't affect the fruit set of *Vitis vinifera* cv. Semillon. In addition, higher total cloud cover anomaly was negatively correlated with the date of occurrence of fruiting events (stages 7 and 8). This may suggest the direct effect of lower solar radiation on these phenological stage. Candolfi-Vasconcelos and Koblet (1990) reported that environmental stress and canopy shade may diminish fruit set of grapevines. Moreover, during the early stages of vegetative growth, strong winds play a major role in determining the production of grapevines. It can break off the new shoots, delaying and even reducing the amount of flowering (Jones, 2015). This explains why abnormally high annual wind speed was negatively correlated with budburst, flowering, and fruit set.

5. Conclusions

The shift in climate conditions between 1997 and 2019 caused early harvest of White and Red Hassaoui, with a minimal reduction in yield of both varieties. Until current date, these grape varieties could adapt to extremes in climate factors occurring after 1997, however, their performance under continuous climate change conditions should be further studied.

Table 11
Variation of stages 9 to 11 phenological events and yield of Red Hassaoui as affected by year.

Year	Stage 9 (Days)	Stage 10 (Days)	Stage 11 (Days)	Yield (kg ha^{-1})
1979	299 s	313xy	328 s	12210.7e
1980	290p	303tu	319o	13451.5f
1981	288o	300qr	314 l	11255.1ab
1982	302 t	316z	331u	15153.4*n*
1983	291p	304u	320o	15877.3op
1984	299 s	312wx	326r	11754.7 cd
1985	300 s	314y	329st	11844.4d
1986	296qr	308v	322p	14642.6 lm
1987	290p	303tu	319o	13641.6 fg
1988	287no	301rs	316mn	14084.8hij
1989	295q	308v	324q	14535.9kl
1990	284 l	296p	312 k	11542.4bcd
1991	286mn	301rs	315 lm	13842.3ghi
1992	299 s	313xy	328 s	17034.7r
1993	302 t	314y	330tu	14843.5lmn
1994	297r	311w	326r	11268.4ab
1995	288o	301rs	317*n*	18426.8 s
1996	295q	308v	324q	16389.4q
Cluster 1	294.0B	307.0B	322.0B	13988.9B
1997	285 lm	299q	314 l	15874.2op
1998	274i	287jk	303 h	14276.1jk
1999	288o	302st	317*n*	11542.4bcd
2000	288o	301rs	317*n*	12433.2e
2001	279 k	291*n*	306i	11126.2a
2002	274i	288kl	303 h	11814.3d
2003	274i	287jk	303 h	15978.6p
2004	278 k	290mn	305i	14943.3mn
2005	268ef	281e	297de	13874.4ghi
2006	272gh	286ij	301 fg	16842.3r
2007	272gh	284gh	300f	13769.8fgh
2008	279 k	293o	308j	11423.7abc
2009	272gh	285hi	301 fg	13752.2fgh
2010	269f	281e	296d	11154.3a
2011	276j	289 lm	305i	14186.4ijk
2012	273hi	287jk	302gh	13844.6ghi
2013	271 g	283 fg	298e	15567.4o
2014	268ef	282ef	297de	11754.2 cd
2015	261c	274c	290c	14266.9jk
2016	251a	263a	278a	13569.3 fg
2017	258b	271b	287b	15736.6op
2018	264d	276d	291c	12468.7e
2019	267e	281e	296d	14254.9jk
Cluster 2	272.2 A	285.3 A	300.6 A	13671.9 A

Stage 9: beginning of veraison, stage 10: full veraison, stage 11: harvest. Means within the same row followed by the same letters are not significantly different at $P < 0.05$ according to Duncan's multiple range test.

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