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DOI:10.1021/jf203254k

Varietal Relationship Between Instrumental Skin Hardness and Climate for Grapevines (*Vitis vinifera* L.)

Running title: Instrumental Skin Hardness and Climate for Grapevines

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ABSTRACT

The main aims of this work were to classify thirty colored and white wine grape varieties according to the berry skin hardness, to assess the influence of annual variations in climate on the berry skin hardness and to establish significant relationships among berry skin mechanical properties and some climatic-bioclimatic indices calculated for different grape ripening periods, close to the harvest date. The results obtained show that the most influential bioclimatic indices on the skin mechanical attributes were temperature parameters. In a same season, the influence of the production area was also evaluated, precipitation parameters being the best correlated with the berry skin hardness. This first work has permitted to know the relationship among skin texture characteristics and seasonal climatic indices.

KEYWORDS: puncture test; berry skin hardness; grape varieties; bioclimatic index

INTRODUCTION

The oenological potential of the grapes used for the elaboration of high quality wines depends on berry attributes. In fact, it is demonstrated that grape chemical composition, in particular the phenol profile, is influenced by several agroecological factors like cultivar, climate, soil type and agronomical practices *(1-3)*. The relationship between climate and berry properties has attracted considerable attention as it affects wine quality *(4-6)*. In particular, temperature is recognized as the main climatic variable affecting the vintage quality *(7, 8)*. The length of the growing season is also considered a determining factor of grape composition *(4, 7, 9)*.

In addition, it is well-known that grape composition changes continuously during ripening period. However, the seasonal variability in climate can modify the magnitude of such changes, which implies modifications in wine quality. So, some authors emphasize the relevance of annual variations in climate because these ones, in addition to vineyard location, typically far outweigh any changes in berry attributes introduced by cultural practices *(2)* and even those arising from differences in soil conditions *(10-12)*.

Phenolic compounds, extractable from grape skins and seeds, have a notable influence on the quality of red wines. In this sense, the skin hardness, evaluated by the skin break force and skin break energy parameters, as well as the skin thickness are considered mechanical properties adequate for the estimation of the skin cell-wall degradability and, therefore, of the extractability of anthocyanins from berry skin to must/wine *(13, 14)*. On the other hand, the efficiency of skin mechanical properties for the differentiation of varieties, production areas and even vineyards has been recently assessed *(15)*. Within the same variety, the values of the textural parameters are also heavily influenced by growing area *(16-18)* whereas a smaller influence on these skin mechanical properties is imputable to grape ripening stages *(17, 19)*. In different years, same vineyards showed grapes with different skin mechanical characteristics *(15)*. Seasonal variations are widely accepted in viticulture as a well-recognized factor that can mask other environmental and cultural effects on berry features. However, no study has been published up till now on the effect of climatic elements on berry textural parameters.

Therefore, the influence of different climatic variables on berry skin mechanical properties was studied in this work. The main aims proposed were: i) to classify thirty colored and white wine grape varieties according to the berry skin hardness in two consecutive years; ii) to assess the influence of annual variations in climate on skin mechanical attributes during five consecutive years; iii) to establish correlations among the berry skin hardness and several climatic-bioclimatic indices.

MATERIALS AND METHODS

Grape samples. For the varietal study of the skin texture, grape samples of 7 white and 23 colored cultivars, all of them belong to *Vitis vinifera* L., were harvested in the same collection-experimental vineyard located in Piedmont (North-West Italy) in 2006 and 2007 (**Table 1**). To establish the relationships among the berry skin hardness and the climatic-bioclimatic indices, Arneis (ARN), Moscato bianco (MOB) and Nebbiolo (NE) wine grapes were also harvested in 2008, 2009 and 2010. Moreover, with the aim of relating, for each cultivar, the differences in the skin hardness with the seasonal climatic and bioclimatic parameters, Barbera (BAR), Freisa (FRE), MOB and NE grape samples were harvested in 2008 from four, five, two and four homogeneous commercial vineyards (vine age, yield, cultural practices, clone), respectively, located in several production areas of the Piedmont.

Each sample consisted of 400 grape berries with attached pedicels, which were randomly picked up from different plants. Once in the laboratory, berries of each cultivar were visually inspected before analysis and those ones with damaged skins were discarded. All samples were harvested when the technological maturity was optimal for the production of the respective wines in agreement with the different Denomination of Origin production disciplinary.

Instrumental Texture Analysis. For each cultivar, a set of 20 berries was randomly sampled *(20)*. The skin hardness was assessed by a puncture test carried out by a Universal Testing Machine (UTM) TAxT2i Texture Analyzer (Stable Micro System, Godalming, Surrey, UK) equipped with a HDP/90 platform, P/2N needle probe and a 5 kg load cell. Test speed was 1 mm/s and the penetration applied was 3 mm. All the data acquisitions were made at 400 Hz, involving the Texture Expert Exceed software, version 2.54 for Windows. The berries were placed on the metal plate of the UTM with the pedicel in a horizontal plane in order to be consistently punctured in the lateral side. The berry skin hardness was assessed by the maximum break force (F_{sk}) or by the break energy (W_{sk}) *(21)*. The first parameter corresponds to the skin resistance to the needle probe penetration and it is expressed in N. The second parameter is represented by the area under the curve, which is limited between 0 and $F_{sk,}$ and it is expressed in mJ *(21)*. The use of needle probe allows the only estimation of this skin mechanical characteristic, minimizing the possible interferences caused on the results by the pulp firmness.

Physicochemical determinations. For each cultivar, the remaining berries were used for determining physicochemical parameters in the grape must obtained by manual crushing and filtration. In the juice obtained, ºBrix were determined by refractometry using Atago refractmeter (Japan). pH, total acidity and reducing sugars were determined according to European Official Methods *(22)*. Organic acids (malic acid, tartaric acid and citric acid) and reducing sugars (glucose and fructose) were quantified by HPLC (Thermo Electron Corporation, Waltham, MA, USA) using an UV detector (UV100) at 210 nm and a refractive index detector (RI-150), respectively. The analyses were performed isocratically at 0.8 mL/min and 65 °C with a 300 x 7.8 mm i.d. cation exchange column (Aminex HPX-87H) and a Cation H^+ Microguard cartridge (Bio-Rad Laboratories, Hercules, CA, USA). The mobile phase was 0.0065 mol/L sulphuric acid.

Climatic and bioclimatic indices. Climatic variables were measured using a Vantage PRO2 weather station (Davis Instruments, Hayward, USA), located into the vineyards or close to them (maximum distance of 250-300 m), and the following bioclimatic indices were calculated for different grape ripening periods (3, 7, 15, 31, 45 and 90-120 days prior to the harvest date for each variety): average daily minimum temperature (AMmT; ºC), average daily maximum temperature (AMxT; ºC), average daily mean temperature (AT; ºC), average daily minimum humidity (AMmH; %), average daily maximum humidity (AMxH; %), average daily mean humidity (AH; %), total precipitations (TP; mm), daily maximum precipitations (MxP; mm), average daily thermal excursion (ATE; ºC), leaf wetness duration (LWD; min), daily maximum duration of leaf wetness (MxDLW; min), absolute minimum temperature (AbMmT; ºC), absolute maximum temperature (AbMxT; ºC), number of frost days (DI0; days), number of rainy days (rain ≥ 1 mm) (DP1; days), thermal sum over a 10° C threshold (TP10; ºC), Huglin index (HI; ºC) *(23)* and total thermal excursion (TTE; ºC).

Statistical analysis. All statistical analyses were performed using the SPSS software version 11.5 for Windows (SPSS Inc., Chicago, IL, USA). The Tukey-b test for $p < 0.05$ was used in order to establish statistical differences by one-way analysis of variance (ANOVA). A cluster analysis was performed to classify wine grape varieties according to their berry skin mechanical properties using Ward method and squared Euclidean distance. Pearson correlation coefficients were calculated to determine significant relationships among the berry skin hardness and the bioclimatic indices studied.

RESULTS AND DISCUSSION

Characterization and classification of wine grape varieties according to berry skin hardness. Table 2 shows the values of the break force and energy of the berry skin determined at harvest in two consecutive years (2006 and 2007) for the 30 varieties harvested in the same vineyard. In general, the grapes harvested in 2007 year were softer than those ones harvested in 2006 year as indicated by the lower values of break force and energy of berry skin in 2007 year. The harder varieties were Teinturier rotondo (TER) (0.815 N) and Becuet (BEC) (0.591 N) in 2006 and 2007 years, respectively, according to the berry skin break force whereas the greater values of berry skin break energy were associated with Teinturier ellittico (TEE) (0.735 mJ) and Nascetta (NAS) (0.555 mJ) in 2006 and 2007 years, respectively. On the other hand, the softer varieties were Nebue (NEB) (0.443 N), and Cortese (COR) and NEB (0.338-

0.342 N) in 2006 and 2007 years, respectively, taking into account the berry skin break force whereas the lower values of berry skin break energy corresponded to Cari-Pelaverga (CP), NE, Malvasia di Schierano (MAS), Jacquez (UF), NEB and Moscato d´Amburgo (MOA) (0.295-0.305 mJ) in 2006 year but Neirano-Bouschet Alicante (NA) (0.148 mJ) in 2007 year. Using the mechanical parameters at harvest as variables, ANOVA did not permit to differentiate all cultivars and, therefore, they were classified by cluster analysis in both 2006 and 2007 years (**Figures 1 and 2**). The differences found in the skin hardness for the different grape varieties analyzed confirm that this parameter can be considered as a varietal marker *(19)*. In fact, the two clusters permitted a similar classification of the grape varieties studied. Only few varieties were differently placed in the dendrograms in the two years considered. So, the first cluster corresponding to 2006 year contains UF and Brachetto Roero (BRR) varieties that are included in the second cluster corresponding to 2007 year. Furthermore, Cabernet sauvignon (CS), Neretto duro (NER), Pignolo spano (PS) and Gamba di pernice (GP) varieties are located in the second cluster in 2006 year whereas they are associated with the first cluster in 2007 year. A possible explanation could be the higher variation in the values of the skin break force and skin break energy between both 2006 and 2007 years, respect to other cultivars, for UF (28.5 and 45.2 %), BRR (29.3 and 49.4 %), CS (9.4 and 16.0 %), NER (12.7 and 21.2 %), PS (5.2 and 44.1 %) and GP (1.4 and 22.2 %) varieties. Within these exceptions, although UF, BRR, CS and PS varieties are included in different clusters in 2006 and 2007 years, they are located in the closer sub-clusters. Instead, GP variety showed a more different classification between 2006 and 2007 years as it being located in the more distant sub-clusters.

Regarding the three wine grapes harvested during five consecutive years (2006-2010), in **Figure 3** it can be seen that the hardest skins corresponded to 2009 and 2010, independently on the grape variety studied. In general, the highest values of berry skin break force and energy were associated with ARN whereas the lowest ones corresponded to the aromatic variety MOB.

As previously mentioned, the values of berry skin break force for one given variety are heavily influenced by production area *(16, 17)* and, within this, the different vineyards can be also discriminated *(15)*. In this work, berry skin break force also allowed the differentiation of production areas, particularly for BAR and NE wine grapes (**Figure 4**). Furthermore, it can be observed that the same production area did not cause the same effect on the skin hardness for different grape varieties as consequence of the genotype-environment interaction *(24)*. So, the vineyard 2 involved the greatest values of berry skin break force and energy for BAR but the lowest ones for NE. Likewise, there is the possibility of vineyard adaptation to the environmental conditions, which could modify the response of the variety, and hence grape quality, to the variations in weather parameters. Therefore, it is of great relevance to consider the influence of the bioclimatic indices on mechanical properties of grape varieties.

The physicochemical parameters determined in 2006 and 2007 years at harvest are summarized in **Tables 3 and 4**, respectively. In 2006 and 2007 years, total soluble solids, expressed as ºBrix, varied between 16.2 and 25.8. These values of total soluble solids corresponded to sugar concentrations of 147 and 255 g/L, respectively. Total acidity also varied markedly among the different varieties studied with a variation range of 4.50-15.95. The physicochemical parameters obtained in 2008, 2009 and 2010 years at harvest, as well as those ones determined in BAR, FRE, MOB and NE grape samples harvested from several growing locations, were not shown because they did not contribute to improve the quality of the results discussion. They corresponded to an adequate technological maturity for the production of the respective Denomination of Origin wines.

The parameters that characterize the berry skin hardness (F_{sk} and W_{sk}**)** do not seem to be affected by the technological ripeness parameters of wine grape varieties as the evolution of these two mechanical properties during the ripening period is not clear. Several studies suggested that the behavior of the skin break force close to the harvest could limit the choice of this parameter as a maturity indicator in grape berries. In fact, from veraison to ripeness, an increase in the skin break force is shown, particularly in the first ripening phases, with a steady value or a slight decrease close to the technological maturity *(19, 20, 25)*. A renewed increase was then observed in over-ripe berries *(26)*. With very few exceptions, no significant change was reported in the parameters characterizing the berry skin hardness of Barbera and Cabernet franc grapes containing different soluble solid contents *(17, 18)*.

Taking into account that the values of the physicochemical parameters determined for the cultivars studied correspond to those obtainable in the respective production area, differences in the berry skin hardness can not be attributed to the physicochemical parameters considered.

Annual climatic characteristics. Table 5 shows the climatic and bioclimatic indices corresponding to the grape ripening period of 31 days prior to the different harvest dates in both 2006 and 2007 years whereas **Table 6** reports the ones obtained in 2008, 2009 and 2010 years. These ones are shown because they are better correlated with the berry skin hardness as will be explained later. In general, average daily minimum temperature (AMmT), average daily maximum temperature (AMxT), average daily mean temperature

(AT), thermal sum over a 10° C threshold (TP10) and Huglin index (HI) were higher in 2009 year whereas average daily thermal excursion (ATE) and total thermal excursion (TTE) were higher in 2006 year. On the other hand, average daily maximum temperature (AMxT), average daily thermal excursion (ATE), absolute maximum temperature (AbMxT), Huglin index (HI) and total thermal excursion (TTE) were lower in both 2008 and 2010 years.

The variability in the climatic conditions during the five years studied (2006-2010) can justify the different performance of wine grape varieties as the former do not have the same influence on all the cultivars. Considering the climatic conditions corresponding to the 3 grape growing months closest to harvest, temperature was higher in 2009 year whereas relative humidity and precipitations were higher in 2006 year. So, the frequency of days with maximum temperatures of 30-32 ºC (24.1 %) and 34-36 ºC (23.1 %) was higher in 2009 year, followed by 32-34 ºC (20.9 %) whereas the frequency of days with temperatures higher than 36 ºC represented 13.2 % and the 28-30 ºC range involved 9.8 %. Regarding 2008 year, it resulted to be a warm year because the most usual maximum temperatures were 30-32 ºC (25.2 %) and 28-30 ºC (20.8 %), followed by 32-34 ºC (11.0 %) and 34-36 ºC (5.5 %); temperatures higher than 36 ºC representing only 1.1 %. On the other hand, the percentage of dry days was 68.5, 82.6, 76.1, 78.3 and 75.0 % in 2006, 2007, 2008, 2009 and 2010 years, respectively. Daily precipitations comprised between 10 and 40 mm were found in 5.5, 6.6, 4.4, 2.2 and 4.4 % of the days evaluated in 2006, 2007, 2008, 2009 and 2010 years, respectively. Daily precipitations higher than 60 mm were only found in 2.2 and 1.1 % of the days evaluated in 2006 and 2007 years, respectively. The rainiest days were 14 and 25 September in 2006 year, and 30 August in 2007 year which affected to the latest varieties. Furthermore, **Table 6** shows that the lower values of relative humidity corresponded to the three last years (2008-2010).

Influence and importance of climate on berry skin hardness. A correlation study was performed among different bioclimatic indices and the berry skin hardness. The bioclimatic indices were calculated for different grape ripening periods close to harvest date including 90-120, 45, 31, 15, 7 and 3 days. A period of 90-120 days was selected, depending on the grape variety, in order to consider the time comprised from the berry growth to harvest whereas the period of 45 days involves from veraison *(27)*. Furthermore, a lower number of days were also considered as the last ripening ones being considered to have more influence on grape quality. Thus, the ripening-related accumulation of sugars, anthocyanins, and most flavor and aroma compounds typically coincides with the gradual cooling trend towards the end of the growing season *(28)*.

When the correlation studies were carried out on the differences experienced in both bioclimatic indices and the berry skin hardness between both 2006 and 2007 years for all the varieties analyzed, the highest and most significant correlation factors corresponded to berry skin break energy (W_{sk}) for a time period of 31 days (**Table 7**). These ones were greater than 0.47 at a significance level of $p \leq 0.01$ but they did not increase for a higher number of days considered. The correlation coefficient relative to the relationship between the berry skin break energy and average daily minimum temperature (AMmT) was higher for the 15 days than for the 30 days prior to harvest date. Furthermore, some indices, like average daily mean temperature (AT), thermal sum over a 10 °C threshold (TP10) and Huglin index (HI), only showed significant correlations with the berry skin hardness when they were calculated for the time period of 31 days prior to harvest. On the other hand, other bioclimatic indices were statistically correlated with the berry skin hardness at a time period less than 31 days but the correlation coefficients were lower than 0.47 at a significance level of $p \leq 0.05$.

The correlation study was also performed in the clusters previously differentiated in both 2006 and 2007 years. The best results were obtained for the varieties included in the first clusters and a time period of 31 days with correlation coefficients higher than 0.60 at a significance level of $p \leq 0.05$ but the worst results were associated with the second clusters with correlation factors less than 0.60 at a significance level of $p \leq 0.05$.

The absolute maximum temperature (AbMxT) showed the highest value of the correlation coefficients with berry skin break energy (-0.667, $p \leq 0.01$) in the 31 days prior to harvest which is in good agreement with other studies previously published. So, other authors confirmed that there is a significant association between maximum temperature and wine quality in the 3 or 6 weeks prior to harvest date depending on the Australian wine region studied *(6)*. The same authors reported that years in which maturity is delayed or ripening is slow may need more sunshine hours late in the season and the often associated warm days help to reach the sugar concentration required for fuller-bodied wines. Other authors confirmed that earlier ripening periods in a season may lead to a decrease in grape characteristics and, therefore, in wine quality *(8, 29)*.

The correlation study was also performed on the differences experienced in both bioclimatic indices and the berry skin hardness between two consecutive years for three grape varieties (ARN, MOB and NE) during five years (2006-2010) to verify if the above relationships are maintained along time. In **Table 8**, it can be observed that the highest and most significant correlation factors (> 0.700, $p \leq 0.01$) corresponded to berry skin break force (F_{sk}). When the year's number considered increased from 2 to 5, the mechanical parameter more correlated with climatic and bioclimatic indices changed from berry skin break energy to force. This aspect can be explained by the ability of the berry skin break force to differentiate varieties as it can be considered a potential varietal marker *(19)*. In the first correlation study (30 varieties, 2 years), the variety had a strong weight on the statistical correlations because the differences experienced in both the bioclimatic indices and the berry skin hardness between the two consecutive years are considered. Therefore, it was expected that the significant correlations were found for berry skin break energy. In the second one, the influence of annual variations acquired a higher importance, skin break force being the mechanical parameter more and better correlated with the climatic and bioclimatic indices. In spite of these differences, the absolute maximum temperature (AbMxT) again showed a high value of the correlation coefficient with the berry skin hardness (0.729, $p \leq 0.01$) in the 31 days prior to harvest. In fact, all the significant relationships ($p \leq 0.01$) are associated with the temperature indices in the second correlation study. Furthermore, the correlation coefficients between the skin break force and average daily minimum temperature (AMmT), average daily maximum temperature (AMxT), average daily mean temperature (AT), thermal sum over a 10 ºC threshold (TP10) or Huglin index (HI) increased with the number of days considered.

Another similar study was also carried out on BAR, FRE, MOB and NE grape samples harvested from several growing locations, with the aim of explaining the differences in the berry skin hardness, observed in the different production areas, with the climatic and bioclimatic indices of the respective zones. In this case, when the differences in the temperature parameters among the growing areas were reduced (vintage 2008) with respect to the seasonal variability, the highest and most significant correlation factors (> 0.700, $p \leq 0.01$) corresponded to the berry skin hardness with the precipitation indices, like total precipitations (TP), daily maximum precipitations (MxP) and number of rainy days (rain ≥ 1 mm, DP1), for a time period of 15 and 7 days (**Table 9**). Therefore, water availability in the last ripening weeks seems to be responsible for the skin physical characteristics. The influence of rain on whole berry mechanical properties and skin thickness was already reported for Cabernet franc cultivar *(20)* and Mondeuse grapes during on-vine drying *(26)*, respectively.

The optimum berry temperature for anthocyanin synthesis is around 30 ºC, but above 35 ºC anthocyanins stop accumulating *(30)* or may even be degraded *(31)*. Therefore, average daily maximum temperatures (AMxT) comprised between 22.8 and 31.3 resulted to be adequate for anthocyanin synthesis in the years evaluated. Nonetheless, the influence of temperature on most aroma and flavor compounds is not well understood *(28)*. Moreover, the impact of temperature on harvested grape quality can vary for different grapevine cultivars as consequence of the genotype-environment interaction.

Anthocyanins are particularly important to red wine quality because they are the pigments responsible for red color of grape berries and respective wines *(32)*. Hence the shorter ripening period corresponded to 2007 year and the wine grapes harvested in this year have lower values of berry skin break force and energy, a lesser anthocyanin extraction is expected from red wine grapes to wine. Works previously published on Italian varieties (Brachetto and Nebbiolo grapes) reported that higher skin hardness probably involves greater cell wall fragility and an increase in anthocyanin extraction *(13)*. Taking into account the reported in **Table 8** (more significant data), higher absolute maximum temperatures (AbMxT) seem to be related with a higher berry skin break force and, therefore, with a higher and slower anthocyanin extraction *(14, 25)*.

To conclude, the classification of the wine grape varieties studied in this work attempting to skin mechanical parameters at harvest was rather similar in both 2006 and 2007 years. The differences found in break force and energy of berry skin can probably be due to the genotype-environment interaction *(24)*, the temperature parameters being the stronger correlated indices with the berry skin hardness. Softer skins seem to be characterized by a lesser release of red pigments from grape skin into wine during winemaking process *(14, 25)*. The knowledge of the climatic conditions during the last days of ripening period could help to assess the anthocyanin extractability for a given production area as softer skins were associated with 2007 year and, therefore, with the shorter ripening period. From the results obtained in this work, a complete study of the influence of the different climatic variables on the anthocyanin extractability in red wine grapes, and even on aroma compounds in white wine grapes, in several production areas will be need for a better understanding of the possible effects of climate change on wine grape attributes for the elaboration of high quality wines.

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FIGURE CAPTIONS

Figure 1. Dendogram of wine grape varieties by applying Ward's method hierarchical cluster analysis to their skin mechanical properties at harvest in 2006 year.

Figure 2. Dendogram of wine grape varieties by applying Ward's method hierarchical cluster analysis to their skin mechanical properties at harvest in 2007 year.

Figure 3. Break force (F_{sk}) and break energy (W_{sk}) of berry skin at harvest for Arneis, Moscato bianco and Nebbiolo wine grape varieties during 2006-2010 period.

Figure 4. Break force (F_{sk}) and break energy (W_{sk}) of berry skin at harvest for Barbera, Freisa, Moscato bianco and Nebbiolo wine grape varieties from several production areas. Piedmont vineyards location (town, province): 1- Neive, Cuneo; 2- La Morra, Cuneo; 3- Barbaresco, Cuneo; 4- Carema, Torino; 5- Agliano Terme, Asti; 6- Tortona, Alessandria; 7- Chieri, Torino; 8- Roatto, Asti; 9- Barolo, Cuneo; 10- Casorzo, Asti; 11- Monleale, Alessandria; 12- Calosso, Asti; 13- Carpeneto, Alessandria.

Table 1. List of the cultivars studied, berry color and harvest dates in 2006-2010 period.

Grape variety	Berry color	Harvest date 2006 (day/month)	Harvest date 2007 (day/month)	Harvest date 2008 (day/month)	Harvest date 2009 (day/month)	Harvest date 2010 (day/month)
Arneis (ARN)	White	13/09	29/08	18/09	09/09	21/09
Barbarossa-Uva reina (BUR)	Red	20/09	04/09	-	-	-
Barbera (BAR)	Black	20/09	29/08	-	-	-
Becuet (BEC)	Black	12/09	29/08	-	-	-
Brachetto d´Acqui (BRA)	Black	05/09	21/08	-	-	-
Brachetto Roero (BRR)	Violet	06/09	21/08	-	-	-
Cabernet sauvignon (CS)	Red	20/09	03/09	-	-	-
Cari-Pelaverga (CP)	Red	28/09	11/09	-	-	-
Chardonnay (CHAR)	White	05/09	11/09	-	-	-
Chasselas blanc (CHAS)	White	06/09	04/09	-	-	-
Cortese (COR)	White	13/09	29/08	-	-	-
Croatina (CRO)	Black	13/09	11/09	-	-	-
Dolcetto (DOL)	Black	13/09	04/09	-	-	-
Freisa (FRE)	Black	13/09	29/08	-	-	-
Gamba di pernice (GP)	Black	28/09	03/09	-	-	-
Jacquez (UF, interspecific hybrid)	Black	20/09	04/09	-	-	-
Malvasia bianca (MAB)	White	13/09	29/08	-	-	-
Malvasia di Schierano (MAS)	Violet	13/09	29/08	-	-	-
Moscato d’Amburgo (MOA)	Black	13/09	21/08	-	-	-
Moscato bianco (MOB)	White	06/09	21/08	10/09	26/08	09/09
Moscato nero d´Acqui (MNA)	Black	20/09	11/09	-	-	-
Nascetta (NAS)	White	12/09	11/09	-	-	-
Nebbiolo (NE)	Black	20/09	04/09	08/10	02/10	01/10
Nebue (NEB)	Black	05/09	21/08	-	-	-
Neirano-Bouschet Alicante (NA)	Black	28/09	11/09	-	-	-
Neretto duro (NER)	Black	06/09	21/08	-	-	-
Pignolo spano (PS)	Black	20/09	04/09	-	-	-
Pinot noir (PIN)	Black	05/09	21/08	-	-	-
Teinturier ellittico (TEE)	Black	06/09	21/08	-	-	-
Teinturier rotondo (TER)	Black	06/09	21/08	-	-	-

Table 2. Break force (F_{sk}) and break energy (W_{sk}) of berry skin at harvest for wine grape varieties in 2006 and 2007

Grape variety	F_{sk} (N)			W_{sk} (mJ)		
	2006	2007	Sign^2	2006	2007	Sign^2
Arneis (ARN)	0.562 ± 0.128^{abcdefg}	0.437 ± 0.069^{abcdef}	***	0.388 ± 0.136^{abcde}	0.239 ± 0.070^{ab}	***
Barbarossa-Uva reina (BUR)	0.671 ± 0.145^{fgh}	0.503 ± 0.103^{defg}	***	0.411 ± 0.141^{abcde}	0.536 ± 0.473^{ef}	ns
Barbera (BAR)	0.783 ± 0.082^{hi}	0.499 ± 0.085^{defg}	***	0.579 ± 0.103^{fg}	0.310 ± 0.106^{abcdef}	***
Becuet (BEC)	0.683 ± 0.142^{gh}	0.591 ± 0.074^{g}	*	0.499 ± 0.172^{def}	0.396 ± 0.080^{abcdef}	*
Brachetto d´Acqui (BRA)	0.604 ± 0.176^{cdefg}	0.437 ± 0.070^{abcdef}	***	0.506 ± 0.199^{ef}	0.244 ± 0.073^{ab}	***
Brachetto Roero (BRR)	0.647 ± 0.080^{efg}	0.457 ± 0.081^{bcdef}	***	0.406 ± 0.109^{abcde}	0.206 ± 0.067^{ab}	***
Cabernet sauvignon (CS)	0.593 ± 0.080^{bcdefg}	0.537 ± 0.116^{fg}	ns	0.308 ± 0.067^{ab}	0.259 ± 0.098^{abc}	ns
Cari-Pelaverga (CP)	0.468 ± 0.127^{ab}	0.388 ± 0.057^{abcd}	*	0.295 ± 0.100^{a}	0.283 ± 0.234^{abcde}	ns
Chardonnay (CHAR)	0.465 ± 0.125^{ab}	0.403 ± 0.051^{abcde}	ns	0.349 ± 0.126^{abc}	0.209 ± 0.042^{ab}	***
Chasselas blanc (CHAS)	0.502 ± 0.127^{abc}	0.436 ± 0.091^{abcdef}	ns	0.321 ± 0.117^{abc}	0.267 ± 0.134^{abcd}	ns
Cortese (COR)	0.502 ± 0.061^{abc}	0.338 ± 0.051^{a}	***	0.316 ± 0.056^{ab}	0.164 ± 0.048^{a}	***
Croatina (CRO)	0.666 ± 0.144^{fgh}	0.512 ± 0.120^{efg}	***	0.393 ± 0.133^{abcde}	0.514 ± 0.445^{cdef}	ns
Dolcetto (DOL)	0.518 ± 0.127^{abcde}	0.449 ± 0.147^{abcdef}	ns	0.387 ± 0.141^{abcde}	0.445 ± 0.336^{bcdef}	ns
Freisa (FRE)	0.669 ± 0.114^{fgh}	0.518 ± 0.078^{efg}	***	0.494 ± 0.136^{def}	0.338 ± 0.088^{abcdef}	***
Gamba di pernice (GP)	0.499 ± 0.112^{abc}	0.492 ± 0.081^{defg}	ns	0.315 ± 0.107^{abc}	0.385 ± 0.350^{abcdef}	ns
Jacquez (UF, interspecific hybrid)	0.631 ± 0.031^{defg}	0.451 ± 0.097^{abcdef}	***	0.299 ± 0.045^{a}	0.164 ± 0.064^{a}	***
Malvasia bianca (MAB)	0.648 ± 0.129^{efg}	0.530 ± 0.095^{fg}	**	0.453 ± 0.180^{cdef}	0.279 ± 0.098^{abcde}	***
Malvasia di Schierano (MAS)	0.542 ± 0.130^{abcdef}	0.467 ± 0.058^{bcdef}	*	0.299 ± 0.102^{a}	0.216 ± 0.045^{ab}	**
Moscato d'Amburgo (MOA)	0.513 ± 0.070^{abcd}	0.401 ± 0.109^{abcde}	***	0.305 ± 0.071^{a}	0.231 ± 0.269^{ab}	ns
Moscato bianco (MOB)	0.463 ± 0.069^{ab}	0.373 ± 0.086^{abc}	***	0.342 ± 0.100^{abc}	0.201 ± 0.107^{ab}	***
Moscato nero d´Acqui (MNA)	0.517 ± 0.064^{abcd}	0.443 ± 0.117^{abcdef}	*	0.313 ± 0.077^{abc}	0.309 ± 0.291^{abcdef}	ns
Nascetta (NAS)	0.491 ± 0.139^{abc}	0.480 ± 0.139^{cdefg}	ns	0.364 ± 0.162^{abcd}	0.555 ± 0.393^{f}	ns
Nebbiolo (NE)	0.515 ± 0.070^{abcd}	0.430 ± 0.113^{abcdef}	**	0.297 ± 0.059^{a}	0.381 ± 0.366^{abcdef}	ns
Nebue (NEB)	0.443 ± 0.077^{a}	0.342 ± 0.093^{a}	**	0.301 ± 0.086^{a}	0.187 ± 0.090^{ab}	***
Neirano-Bouschet Alicante (NA)	0.562 ± 0.109^{abcdefg}	0.362 ± 0.078^{ab}	***	0.364 ± 0.137^{abcd}	0.148 ± 0.072^{a}	***
Neretto duro (NER)	0.566 ± 0.121^{abcdefg}	0.494 ± 0.111^{defg}	ns	0.318 ± 0.106^{abc}	0.251 ± 0.136^{ab}	ns
Pignolo spano (PS)	0.570 ± 0.105^{abcdefg}	0.541 ± 0.204^{fg}	ns	0.363 ± 0.121^{abcd}	0.523 ± 0.493^{def}	ns
Pinot noir (PIN)	0.667 ± 0.147^{fgh}	0.524 ± 0.118^{fg}	**	0.448 ± 0.160^{bcde}	0.340 ± 0.193^{abcdef}	ns
Teinturier ellittico (TEE)	0.656 ± 0.073^{fg}	0.540 ± 0.104^{fg}	***	0.735 ± 0.121^{h}	0.415 ± 0.164^{abcdef}	***
Teinturier rotondo (TER)	0.815 ± 0.101^{i}	0.537 ± 0.116^{fg}	***	0.632 ± 0.105^{gh}	0.285 ± 0.138^{abcde}	***
Sign^1	***	***		***	***	

All data are expressed as average value ± standard deviation (n=20). Different Latin letters within the same column indicate significant differences (Sign[1]) among varieties in the same year (*Tukey-b test*; $p < 0.05$). Sign[2] indicates significant differences among the two years for the same variety. [1,2]: *,**,*** and ns indicate significance at $p < 0.05$, 0.01, 0.001 and not significant, respectively.

Table 3. Physicochemical parameters at harvest for wine grape varieties in 2006 year

Grape variety	Brix	Sugars (g/L)	Glucose/Fructose	pH	Total acidity (g/L)	Tartaric acid (g/L)	Malic acid (g/L)	Citric acid (g/L)
Arneis (ARN)	22.1	214	0.992	3.19	7.10	7.92	2.04	0.13
Barbarossa-Uva reina (BUR)	22.1	214	1.059	3.43	6.80	5.81	2.77	0.25
Barbera (BAR)	22.3	216	1.085	3.04	10.20	8.10	2.88	0.23
Becuet (BEC)	19.6	185	1.038	3.06	14.30	10.39	7.95	0.37
Brachetto d´Acqui (BRA)	25.0	246	1.081	3.30	8.30	6.60	3.36	0.30
Brachetto Roero (BRR)	22.0	213	0.999	3.10	9.80	9.37	4.24	0.19
Cabernet sauvignon (CS)	22.8	221	1.105	3.35	7.80	6.71	3.45	0.28
Cari-Pelaverga (CP)	17.6	162	1.059	3.22	5.50	4.63	2.06	0.17
Chardonnay (CHAR)	23.7	231	0.990	3.30	8.00	7.79	3.19	0.22
Chasselas blanc (CHAS)	17.9	166	1.026	3.20	7.40	5.83	2.92	0.14
Cortese (COR)	19.4	183	0.954	3.11	8.30	8.03	2.41	0.18
Croatina (CRO)	22.6	219	1.003	3.13	9.00	9.85	2.43	0.30
Dolcetto (DOL)	22.4	217	0.999	3.32	5.60	6.75	1.89	0.12
Freisa (FRE)	21.7	209	1.004	3.19	8.60	8.00	3.27	0.17
Gamba di pernice (GP)	19.7	186	1.068	3.29	6.10	5.07	2.48	0.28
Jacquez (UF, interspecific hybrid)	20.4	195	1.084	3.30	12.80	5.90	8.34	0.63
Malvasia bianca (MAB)	16.2	147	0.956	3.06	8.20	6.51	3.32	0.22
Malvasia di Schierano (MAS)	19.4	183	0.991	3.08	9.20	9.33	3.00	0.17
Moscato d'Amburgo (MOA)	19.5	183	1.027	3.28	7.90	5.76	4.24	0.31
Moscato bianco (MOB)	23.5	229	0.944	3.12	8.60	7.84	3.15	0.22
Moscato nero d´Acqui (MNA)	18.9	178	1.000	3.55	5.60	6.79	3.02	0.22
Nascetta (NAS)	23.5	229	0.981	3.25	4.60	5.89	0.80	0.10
Nebbiolo (NE)	23.0	224	1.052	3.07	8.40	8.35	1.42	0.18
Nebue (NEB)	23.6	230	0.944	3.01	11.00	9.80	3.69	0.20
Neirano-Bouschet Alicante (NA)	18.5	174	1.117	3.26	8.50	5.29	3.76	0.32
Neretto duro (NER)	16.5	153	1.064	3.17	9.90	5.77	5.14	0.26
Pignolo spano (PS)	22.0	213	1.053	3.28	6.50	6.72	1.72	0.34
Pinot noir (PIN)	25.8	255	1.072	3.35	6.40	5.64	0.23	0.22
Teinturier ellittico (TEE)	21.3	204	1.034	3.27	10.40	7.89	4.15	0.21
Teinturier rotondo (TER)	22.1	214	0.990	3.61	5.90	7.21	2.65	0.27

Table 4. Physicochemical parameters at harvest for wine grape varieties in 2007 year

Grape variety	Brix	Sugars (g/L)	Glucose/Fructose	pH	Total acidity (g/L)	Tartaric acid (g/L)	Malic acid (g/L)	Citric acid (g/L)
Arneis (ARN)	25.1	248	0.989	3.30	6.40	7.60	1.93	0.12
Barbarossa-Uva reina (BUR)	23.2	226	1.002	3.65	4.50	5.27	1.87	0.24
Barbera (BAR)	20.8	201	1.031	3.00	13.55	10.20	4.82	0.32
Becuet (BEC)	18.8	177	1.055	3.05	15.70	11.02	6.05	0.13
Brachetto d´Acqui (BRA)	20.9	200	1.015	3.14	8.40	7.33	2.76	0.07
Brachetto Roero (BRR)	20.8	199	1.012	3.16	7.45	6.47	3.07	0.11
Cabernet sauvignon (CS)	21.5	209	1.066	3.27	8.90	8.38	3.70	0.22
Cari-Pelaverga (CP)	18.2	169	0.988	3.37	5.35	5.03	1.73	0.13
Chardonnay (CHAR)	22.5	219	0.989	3.39	6.65	6.80	2.24	0.13
Chasselas blanc (CHAS)	17.5	162	0.925	3.37	5.25	5.20	1.55	0.08
Cortese (COR)	20.3	194	0.957	3.27	7.05	7.53	1.60	0.11
Croatina (CRO)	22.1	216	1.007	3.18	8.85	9.81	1.65	0.19
Dolcetto (DOL)	20.0	190	0.975	3.26	5.85	7.31	0.73	0.08
Freisa (FRE)	21.9	211	1.021	3.16	9.15	7.99	3.31	0.16
Gamba di pernice (GP)	19.9	188	1.038	3.28	6.70	5.10	2.93	0.28
Jacquez (UF, interspecific hybrid)	21.8	198	1.017	3.00	15.95	7.18	10.44	0.50
Malvasia bianca (MAB)	17.9	167	0.978	3.12	7.95	6.46	3.05	0.14
Malvasia di Schierano (MAS)	20.3	194	0.999	3.20	7.95	7.48	2.30	0.12
Moscato d'Amburgo (MOA)	19.0	178	1.029	3.23	7.65	6.15	2.92	0.14
Moscato bianco (MOB)	19.2	181	0.987	3.34	5.70	5.79	1.87	0.17
Moscato nero d´Acqui (MNA)	18.0	167	0.982	3.43	6.50	6.61	2.49	0.13
Nascetta (NAS)	22.9	222	1.063	3.42	5.10	5.94	0.59	0.12
Nebbiolo (NE)	23.2	226	1.008	3.01	9.00	8.88	1.82	0.10
Nebue (NEB)	22.8	221	1.026	3.16	8.80	7.71	1.98	0.14
Neirano-Bouschet Alicante (NA)	20.0	190	1.074	3.31	7.70	7.24	3.43	0.08
Neretto duro (NER)	16.2	147	1.024	3.26	8.85	5.85	4.19	0.21
Pignolo spano (PS)	21.9	211	1.010	3.34	7.20	6.98	2.54	0.21
Pinot noir (PIN)	23.8	232	1.006	3.44	6.30	6.21	2.42	0.16
Teinturier ellittico (TEE)	19.2	181	1.003	3.18	11.40	9.49	4.41	0.10
Teinturier rotondo (TER)	20.1	191	1.023	3.64	5.45	5.94	2.10	0.13

Table 5. Climatic and bioclimatic indices corresponding to the grape ripening period of 31 days prior to the different harvest dates (day/month/year) in 2006 and 2007

Index	05/09/06	06/09/06	12/09/06	13/09/06	20/09/06	28/09/06	21/08/07	29/08/07	03/09/07	04/09/07	11/09/07
AMmT (°C)	14.0	14.1	14.2	14.2	14.3	14.0	16.1	15.8	15.5	15.4	14.3
AMxT (°C)	29.7	29.9	29.6	29.7	29.1	27.4	30.6	29.5	29.3	29.1	28.7
AT (°C)	21.0	21.1	20.9	21.0	20.7	19.8	22.8	22.0	21. 5	21.4	20.6
AMmH (%)	51.9	52.1	54.8	54.7	57.4	64.1	54.4	58.9	61.5	61.8	60.0
AMxH (%)	99.8	99.8	100.0	100.0	100.0	100.0	99.8	99.8	100.0	100.0	100.0
AH (%)	84.3	84.3	86.6	86.4	87.0	89.5	81.0	84.4	88.1	88.1	88.4
TP (mm)	10.8	10.8	19.2	19.2	123.6	211.2	56.6	48.6	126.4	126.4	100.0
MxP (mm)	4.6	4.6	9.0	9.0	97.8	97.8	19.2	19.2	61.4	61.4	61.4
ATE (°C)	15.7	15.8	15.4	15.5	14.8	13.5	14.5	13.7	13.8	13.7	14.4
LWD (min)	10081	10262	11296	11027	12690	14446	9002	10568	13271	13433	11916
MxDLW (min)	769	769	818	818	1425	1440	932	932	947	947	947
AbMmT (°C)	9.0	9.0	9.0	9.0	9.0	9.0	13.0	12.3	12.3	12.3	6.8
AbMxT (°C)	36.1	36.1	36.1	36.1	36.1	36.1	37.1	36.3	33.9	33.9	33.6
DI0 (days)	0	0	0	0	0	0	0	0	0	0	0
DP1 (days)	3	3	4	4	5	8	7	7	9	9	6
TP10 (°C)	380.0	383.2	381.5	382.2	373.6	342.9	428.0	405.5	396.5	392.4	367.7
HI (°C)	515.3	519.4	514.4	515.9	502.0	459.5	554.8	525.6	517.1	511.9	492.6
TTE (°C)	501.3	504.0	491.3	494.4	474.4	430.4	463.9	439.5	441.9	437.8	461.0

AMmT = average daily minimum temperature, AMxT = average daily maximum temperature, AT = average daily mean temperature, AMmH = average daily minimum humidity, AMxH = average daily maximum humidity, AH = average daily mean humidity, TP = total precipitations, MxP = daily maximum precipitations, ATE = average daily thermal excursion, LWD = leaf wetness duration, MxDLW = daily maximum duration of leaf wetness, AbMmT = absolute minimum temperature, AbMxT = absolute maximum temperature, DI0 = number of frost days, DP1 = number of rainy days (rain ≥ 1 mm), TP10 = thermal sum over a 10 °C threshold, HI = Huglin index, TTE = total thermal excursion.

Table 6. Climatic and bioclimatic indices corresponding to the grape ripening period of 31 days prior to the different harvest dates (day/month/year) in 2008, 2009 and 2010

Index	10/09/08	18/09/08	08/10/08	26/08/09	09/09/09	02/10/09	09/09/10	21/09/10	01/10/10
AMmT (°C)	16.5	14.4	11.7	18.7	17.6	14.3	15.6	14.5	13.1
AMxT (°C)	28.3	27.3	22.8	31.3	30.9	29.3	26.3	27.2	24.7
AT (°C)	22.1	20.5	16.5	24.6	23.8	20.4	20.5	20.2	18.3
AMmH (%)	43.2	51.1	47.5	42.5	41.3	48.4	68.9	47.1	50.1
AMxH (%)	88.3	100.0	89.6	87.6	93.3	93.1	96.4	96.0	93.2
AH (%)	66.8	80.6	70.6	65.7	68.3	75.8	86.7	74.5	73.4
TP (mm)	6.4	21.4	14.2	45.0	22.0	73.2	67.2	37.0	57.6
MxP (mm)	4.0	10.0	5.4	32.6	21.0	41.6	32.4	28.0	17.0
ATE (°C)	11.8	13.0	11.0	12.6	13.2	15.0	10.8	12.7	11.6
LWD (min)	10168	14929	10059	8477	6951	14143	13282	13952	11830
MxDLW (min)	864	1237	1188	968	794	1388	1406	1285	1440
AbMmT (°C)	11.9	6.2	5.3	14.7	11.1	11.6	9.4	9.1	8.7
AbMxT (°C)	32.9	31.9	30.5	35.0	34.8	37.6	31.4	32.7	28.2
DI0 (days)	0	0	0	0	0	0	0	0	0
DP1 (days)	2	3	4	4	1	5	7	4	7
TP10 (°C)	396.4	347.0	232.3	480.5	455.9	377.8	350.0	348.2	285.0
HI (°C)	500.5	459.8	327.1	592.8	573.1	507.6	444.9	458.7	385.2
TTE (°C)	377.5	415.0	353.4	402.9	423.8	479.4	344.8	406.3	370.6

AMmT = average daily minimum temperature, AMxT = average daily maximum temperature, AT = average daily mean temperature, AMmH = average daily minimum humidity, AMxH = average daily maximum humidity, AH = average daily mean humidity, TP = total precipitations, MxP = daily maximum precipitations, ATE = average daily thermal excursion, LWD = leaf wetness duration, MxDLW = daily maximum duration of leaf wetness, AbMmT = absolute minimum temperature, AbMxT = absolute maximum temperature, DI0 = number of frost days, DP1 = number of rainy days (rain ≥ 1 mm), TP10 = thermal sum over a 10 °C threshold, HI = Huglin index, TTE = total thermal excursion.

Table 7. Correlation coefficients among different climatic and bioclimatic indices and berry skin hardness for different grape ripening periods close to harvest date in 2006 and 2007

Index	90-120 days		45 days		31 days		15 days		7 days		3 days	
	F_{sk}	W_{sk}	F_{sk}	W_{sk}	F_{sk}	W_{sk}	F_{sk}	W_{sk}	F_{sk}	W_{sk}	F_{sk}	W_{sk}
AMmT (°C)	ns	-0.519**	ns	ns	ns	-0.533**	ns	-0.616**	ns	-0.401*	ns	ns
AMxT (°C)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
AT (°C)	ns	ns	ns	ns	ns	-0.548**	ns	ns	ns	ns	ns	ns
AMmH (%)	ns	-0.383*	ns	ns	ns	ns	ns	ns	ns	-0.449*	ns	-0.439*
AMxH (%)	ns	-0.492**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
AH (%)	ns	-0.435*	0.371*	0.531**	ns	0.548**	ns	ns	ns	-0.479**	ns	-0.412*
TP (mm)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
MxP (mm)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
ATE (°C)	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.453*	ns	0.460*
LWD (min)	ns	ns	ns	0.390*	0.371*	0.474**	ns	ns	ns	-0.392*	ns	ns
MxDLW (min)	ns	-0.429*	ns	ns	ns	ns	ns	-0.389*	ns	-0.453*	ns	ns
AbMmT (°C)	ns	-0.569**	ns	ns	ns	ns	ns	-0.423*	ns	-0.451*	ns	ns
AbMxT (°C)	ns	ns	ns	0.473**	-0.379*	-0.667**	ns	ns	ns	ns	ns	ns
DI0 (days)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
DP1 (days)	ns	-0.395*	ns	ns	ns	ns	ns	ns	ns	-0.397*	ns	-0.432*
TP10 (°C)	ns	ns	ns	ns	ns	-0.512**	ns	ns	ns	ns	ns	ns
HI (°C)	ns	ns	ns	ns	ns	-0.442*	ns	ns	ns	ns	ns	ns
TTE (°C)	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.452*	ns	0.462*

Berry skin break force (F_{sk}, N), berry skin break energy (W_{sk}, mJ). AMmT = average daily minimum temperature, AMxT = average daily maximum temperature, AT = average daily mean temperature, AMmH = average daily minimum humidity, AMxH = average daily maximum humidity, AH = average daily mean humidity, TP = total precipitations, MxP = daily maximum precipitations, ATE = average daily thermal excursion, LWD = leaf wetness duration, MxDLW = daily maximum duration of leaf wetness, AbMmT = absolute minimum temperature, AbMxT = absolute maximum temperature, DI0 = number of frost days, DP1 = number of rainy days (rain ≥ 1 mm), TP10 = thermal sum over a 10 °C threshold, HI = Huglin index, TTE = total thermal excursion. Significant: *, ** indicate significance at $p \leq 0.05$ and $p \leq 0.01$, respectively, ns = not significant.

Table 8. Correlation coefficients among different climatic and bioclimatic indices and berry skin hardness for different grape ripening periods close to harvest date in 2006-2010 period for ARN, MOB and NE wine grapes

Index	90-120 days		45 days		31 days		15 days		7 days		3 days	
	F_{sk}	W_{sk}	F_{sk}	W_{sk}	F_{sk}	W_{sk}	F_{sk}	W_{sk}	F_{sk}	W_{sk}	F_{sk}	W_{sk}
AMmT (°C)	0.726**	ns	0.714**	0.603*	0.662*	ns	0.600*	ns	0.592*	ns	ns	ns
AMxT (°C)	0.761**	0.644*	0.735**	0.640*	0.750**	ns	0.741**	0.586*	0.721**	0.632*	0.596*	ns
AT (°C)	0.914**	0.696*	0.730**	0.634*	0.708*	ns	0.665*	ns	0.676*	ns	ns	ns
AMmH (%)	-0.689*	ns	-0.680*	ns	ns	ns	ns	ns	ns	ns	ns	ns
AMxH (%)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
AH (%)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
TP (mm)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
MxP (mm)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
ATE (°C)	ns	ns	ns	ns	0.614*	ns	0.667*	0.634*	0.644*	0.704*	0.761**	0.713**
LWD (min)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
MxDLW (min)	ns	-0.606*	ns	-0.668*	ns	-0.662*	ns	ns	-0.702*	-0.622*	ns	-0.581*
AbMmT (°C)	0.646*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
AbMxT (°C)	ns	ns	0.687*	0.589*	0.729**	ns	0.629*	ns	0.649*	0.629*	ns	ns
DI0 (days)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
DP1 (days)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
TP10 (°C)	0.887**	0.663*	0.760**	0.656*	0.739**	0.577*	0.705*	ns	0.695*	ns	ns	ns
HI (°C)	0.820**	0.660*	0.750**	0.652*	0.748**	ns	0.728**	ns	0.714**	0.602*	ns	ns
TTE (°C)	ns	ns	ns	ns	0.614*	ns	0.669*	0.630*	0.646*	0.704*	0.762**	0.715**

Berry skin break force (F_{sk}, N), berry skin break energy (W_{sk}, mJ). AMmT = average daily minimum temperature, AMxT = average daily maximum temperature, AT = average daily mean temperature, AMmH = average daily minimum humidity, AMxH = average daily maximum humidity, AH = average daily mean humidity, TP = total precipitations, MxP = daily maximum precipitations, ATE = average daily thermal excursion, LWD = leaf wetness duration, MxDLW = daily maximum duration of leaf wetness, AbMmT = absolute minimum temperature, AbMxT = absolute maximum temperature, DI0 = number of frost days, DP1 = number of rainy days (rain ≥ 1 mm), TP10 = thermal sum over a 10 °C threshold, HI = Huglin index, TTE = total thermal excursion. Significant: *, ** indicate significance at $p \leq 0.05$ and $p \leq 0.01$, respectively, ns = not significant.

Table 9. Correlation coefficients among different climatic and bioclimatic indices and berry skin hardness for different grape ripening periods close to harvest date in 2008 year in several production areas (BAR = 4, FRE = 5, MOB = 2, NE = 4)

Index	90-120 days		45 days		31 days		15 days		7 days		3 days	
	F_{sk}	W_{sk}	F_{sk}	W_{sk}	F_{sk}	W_{sk}	F_{sk}	W_{sk}	F_{sk}	W_{sk}	F_{sk}	W_{sk}
AMmT (°C)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
AMxT (°C)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
AT (°C)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
AMmH (%)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
AMxH (%)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
AH (%)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
TP (mm)	ns	0.575*	0.560*	0.523*	0.565*	ns	0.750**	0.674**	0.719**	0.703**	ns	ns
MxP (mm)	ns	ns	ns	ns	ns	ns	0.717**	0.664**	0.702**	0.671**	ns	ns
ATE (°C)	ns	ns	ns	ns	ns	ns	ns	ns	-0.598*	-0.605*	ns	ns
LWD (min)	ns	ns	ns	ns	ns	ns	ns	ns	0.585*	ns	0.598*	ns
MxDLW (min)	0.643**	0.575*	0.620*	0.619*	0.604*	0.539*	ns	ns	0.652**	0.552*	0.620*	0.519*
AbMmT (°C)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
AbMxT (°C)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
DI0 (days)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
DP1 (days)	ns	0.531*	ns	0.548*	ns	ns	0.731**	0.629*	0.715**	0.707**	0.610*	0.591*
TP10 (°C)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
HI (°C)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
TTE (°C)	ns	ns	ns	ns	ns	ns	ns	ns	-0.593*	-0.601*	ns	ns

Berry skin break force (F_{sk}, N), berry skin break energy (W_{sk}, mJ). AMmT = average daily minimum temperature, AMxT = average daily maximum temperature, AT = average daily mean temperature, AMmH = average daily minimum humidity, AMxH = average daily maximum humidity, AH = average daily mean humidity, TP = total precipitations, MxP = daily maximum precipitations, ATE = average daily thermal excursion, LWD = leaf wetness duration, MxDLW = daily maximum duration of leaf wetness, AbMmT = absolute minimum temperature, AbMxT = absolute maximum temperature, DI0 = number of frost days, DP1 = number of rainy days (rain ≥ 1 mm), TP10 = thermal sum over a 10 °C threshold, HI = Huglin index, TTE = total thermal excursion. Significant: *, ** indicate significance at $p \leq 0.05$ and $p \leq 0.01$, respectively, ns = not significant.

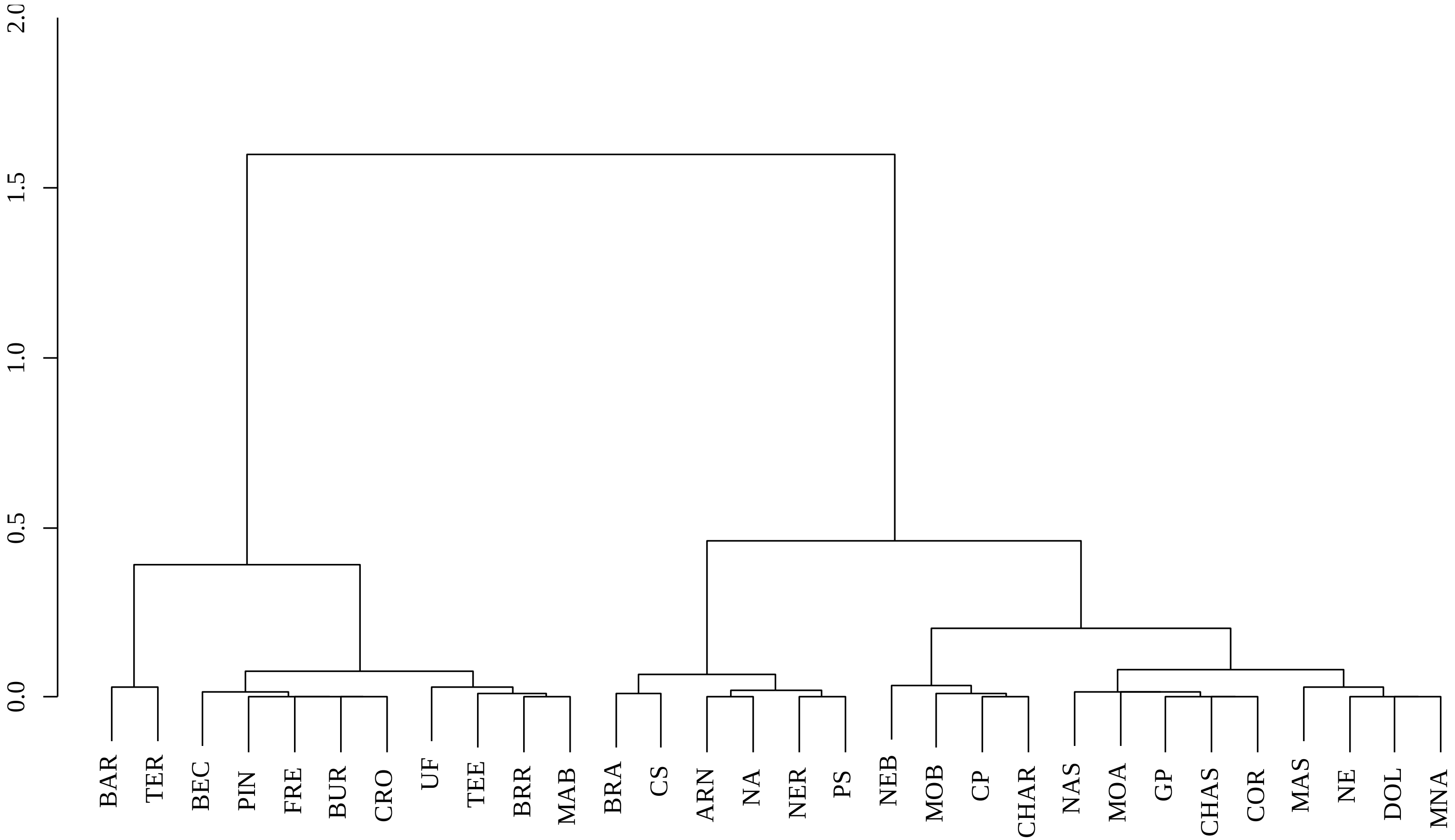
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Figure 1.

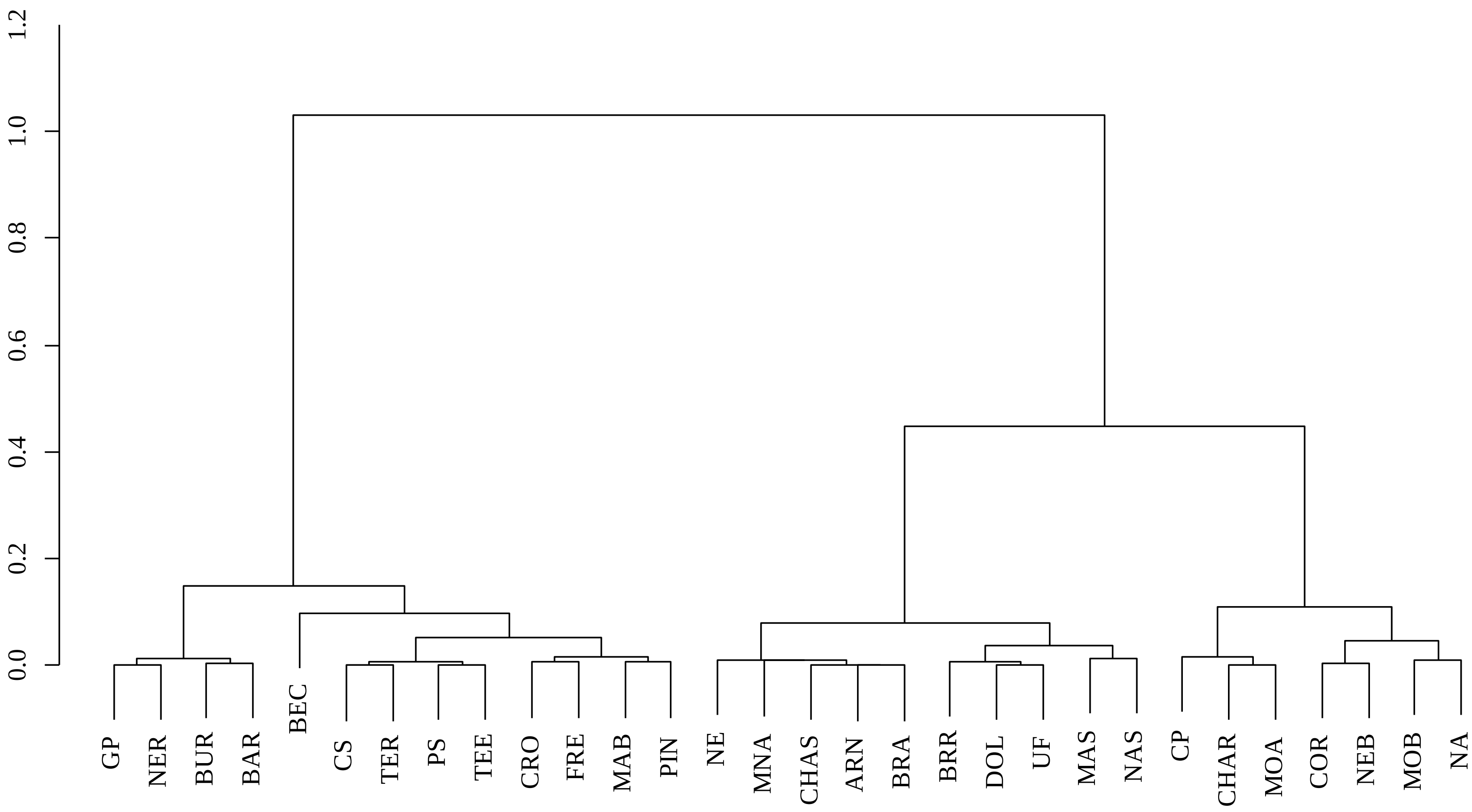
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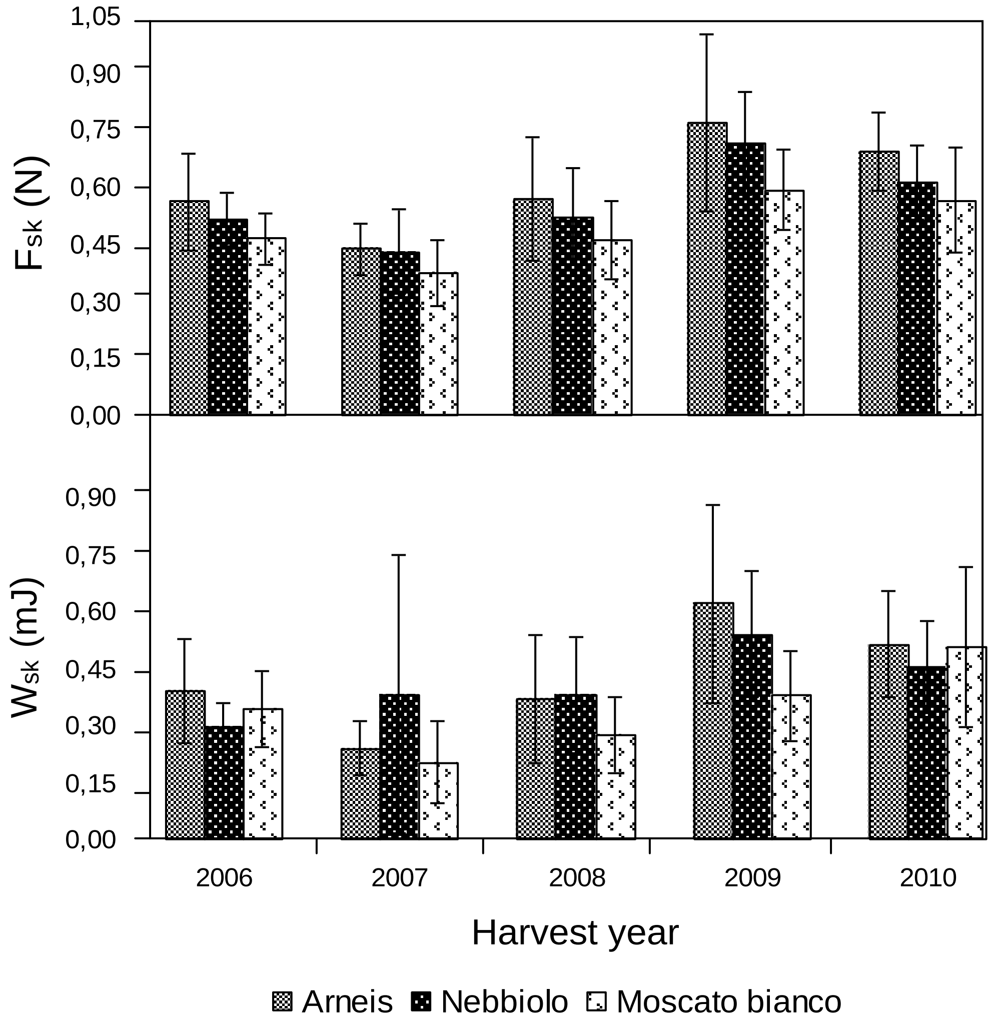
Figure 2.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0,00
F_{sk} (N)
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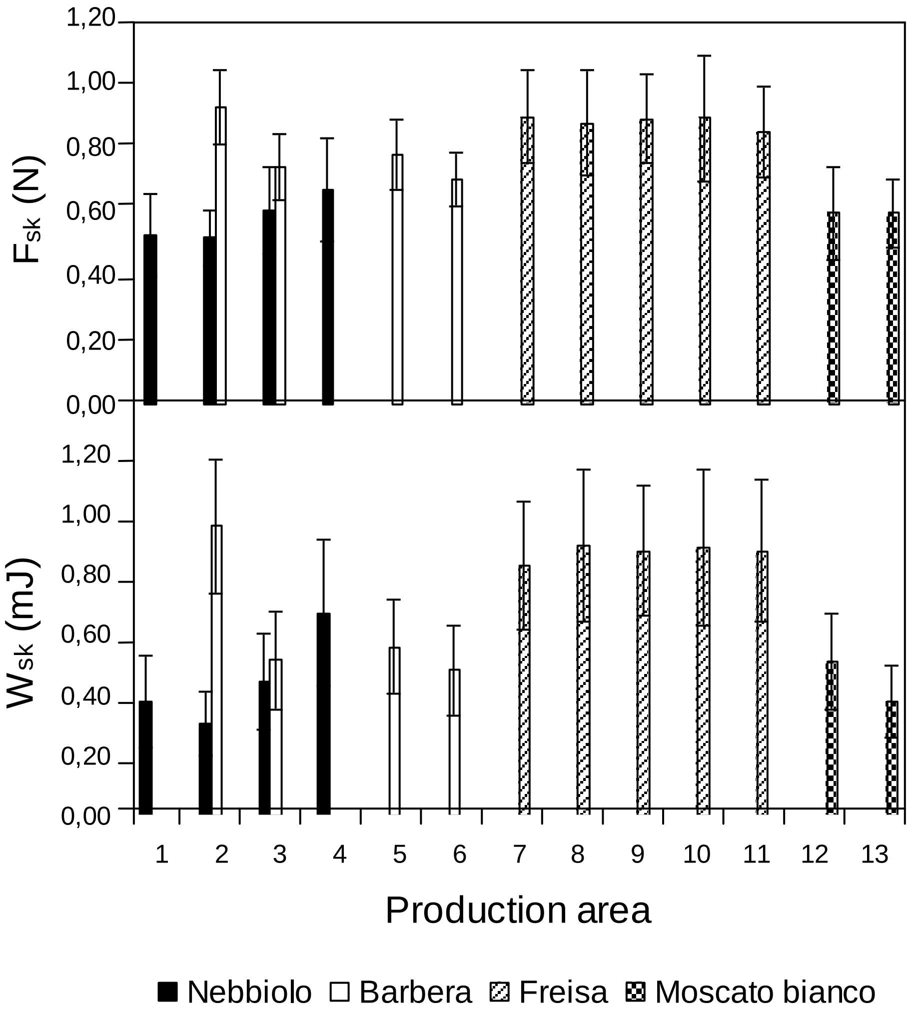
0,60
0,45
0,30
0,15
0,00
W_{sk} (mJ)
2006
2007
2008
2009
2010
Harvest year
Arneis
Nebbiolo
Moscato bianco

Figure 3.



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0,00
F_{sk} (N)
W_{sk} (mJ)
1 2 3 4 5 6 7 8 9 10 11 12 13
Production area
Nebbiolo
Barbera
Freisa
Moscato bianco

Figure 4.