UNIVERSITA' DEGLI STUDI DI NAPOLI FEDERICO II
Dipartimento di Agraria

DOTTORATO DI RICERCA IN
SCIENZE E TECNOLOGIE DELLE PRODUZIONI AGRO-ALIMENTARI

XXVII Ciclo

Climate change: Anti-transpirant effects on grape physiology and berry and wine composition (*Vitis Vinifera L.)*

Coordinatore:
Prof. Giancarlo Barbieri

Dottoranda:
Dott. ssa Nadia Marallo

Tutor:
Prof. Claudio Di Vaio

Anno Accademico 2014 - 2015

Index

0 PREFACE

0.1 Climate change

The intimate connection between viticulture and climate has three important aspects relating to climate change. First, any climate change must obviously contribute to shaping future viticultural terroirs. Given that the vines have a commercial life of 50 or even 100 years, any reliable pointers to future climate must play a crucial part in vineyard planning. Second, historical accounts of vine growing, and of its geographical limits and vintage dates, give valuable insights into past climates. Elucidation of these helps us to esimate how much of present and future climate change might be due to natural causes, since what has happened naturally before can, and almost certainly will, happen naturally again. Only against that background can we start to asses any new contribution of man- caused, or anthropogenic, factors (Gladstones, 2011).

The work of Fairbridge (1962) on world sea levels was a notable early contribution to climate change studies. Based on tidal gauges going back some 300 years and coastal geomorphology before that, he concluded that within the last 1200 years the sea twice exceeded its mid 20th century levels: by about 20 cm in the 9th and early 10th centuries and by up to 40 cm between the mid 11th and early 13th centuries. The latter peak gave evidence of global temperatures at the time significantly above those of the 20th century. Geomorphology then indicated a progressive sea level fall of a metre or more to a minimum in the 15th century, followed by a steep recovery to modern levels though the early to mid 16th century. Fluctuations over the subsequent tidal gauge period have been more subdued: a fall of perhaps 20-30 cm though the 17th century, followed by a rise to near-present levels that persisted though much of the 18th century, renewed fall of up to 20 cm in the early 19th century, and a mostly steady rise from the mid 19th century on. The rate of rise through this last period has averaged about 1.2 mm a year and has shown reasonable correlation with measured air temperatures (Gornitz et al. 1982).

Fairbridge made the important point that, unlike many measures, sea level gives a true indication of world average temperatures because of the hydrostatic continuity of the world water plane. He also underlined the correlations of climate and sea level with solar phenomena, as the following passage from his 1962 paper shows.

The solar constant is very stable, but its ultraviolet emission varies over 200% with the sunspot cycles; this in turn controls the density of the upper atmosphere ozone screen which acts as a thermal blanket to the earth. Furthermore the corpuscular cosmic ‘ray’ streams associated with sunspot periods also play a role. Thus past records of sunspots should reflect climatic patterns. Observations of sunspots and aurora back to 649 BC (Schove 1955) given a pattern that is remarkably reflected by the climatic records, historical and geological. Sea levels, in turn, react to the climatic events with remarkable clarity. The significant feature about the effect of sunspot cycles on climate is that short 11-year cycles play a role that is too short to show a very great sea-level change, only a few cm as a rule. But, if one smooths the sunspot peaks over 100-year periods, the oscillation is almost exactly matched by the general record of mean sea-level.

The most comprehensive other historical and geographical studies of climate over the last two millenia, albeit mostly for Europe, have been those of Le Roy Ladurie (1971), Lamb (1977, 1982, 1984) and Pfister (1984, 1988). Bradley (1991) also gives a useful summary.

These studies present a picture broadly consistent with Fairbridge’s sea levels, particularly for the last millennium for which the information is strongest. The most prominent feature is the marked warmth of the so-called Mediaeval Warm Period, lasting (with some fluctuation) from the ninth to about the late 13th century. During this period sea ice was largely absent from around Iceland and southern Greenland. Viking settlers grew cereals in both regions, and in Greenland they buried their dead deep in soils that later became permanently frozen. Cereal cultivation in Scandinavia extended much further north than now, with wheat grown in the Trondheim district and hardier cereals beyond 69° latitude. Throughout western Europe crop cultivation and treelines went some 200 m higher than in modern times. Glaciers were substantially less extensive than they were to become later, while coastlines corroborated Fairbridge’s geomorphologically-derived estimates of sea levels at the time.

0.1.1 Were the climate changes global?

The extent to which European climatic fluctuations have reflected similar and synchronous fluctuations world-wide has always been controversial. The ‘consensus’ view, as exemplified by P.D. Jones and Mann (2004), and Osborn and Briffa (2004), is that they largely do not. This view emphasizes apparent differences in timing, location, type and extent of climate change within both the Medieval Warm Period and the Little Ice Age, while acknowledging their existence in broad terms.

It is true that climatic changes, by their nature, cannot be fully identical or synchronous across environments. We know that the interiors of continents heat and cool faster than coasts and especially oceans. Regions influenced by the incidence of sea ice or winter snow cover- for instance Siberia- will undergo still greater and faster changes, since the advance of either accelerates local cooling through reflecting solar radiation away, while their retreat conversely accelerates local warming. This is a case of positive feed-back under both warming and cooling. Thus high latitudes of the Northern Hemisphere undergo wider and faster climatic fluctuations than the tropics or the ocean-buffered Southern Hemisphere.

Further, any induced changes in the major ocean currents can impinge differentially on the coasts and hinterlands they influence. The massive inertia of the currents also means that resulting climate changes can persist well after their original impetus has ceased.

These reservations accepted, the available evidence does suggest that the major (e.g. centennial) temperature fluctuations of the historical period have been essentially synchronous across the continents and hemispheres. The evidence comes not only from sea levels, as already described, but also from studies of glaciers (Rothlisberg 1986, cited by Wigley and Kelly 1990; Oerlemans 2005); oxygen isotopes in ice cores (Thompson et al. 1986); and on more detailed time scales from tree-ring and other chronologies (Esper et al. 2002; Cook et al., 2002; Yang et al. 2002).

It is of interest that the Mediaeval Warm Period as delineated in the above studies coincided with often long periods of extreme drought in the Great Plains and California regions of the USA, far exceeding the ‘dust bowl’ of the 1930s (Stine 1994; Laird et al. 1996; Woodhouse and Overpeck 1998; Cook et al. 2004). A generally considered reason was poleward displacement of the weather systems during this warm period, leading to less winter rain in California, and more summer settling of high pressure cells over the plains east of the Rockies that blocked summer rain-bearing winds from the east and south. Similarly Lamb (1977) noted a high incidence of drought from central Europe to central Asia over this period, with low levels of the Caspian Sea. Parallel to the North American droughts, this started to reverse early in the 13th century. During the cooling of the next 200-300 years the Caspian rose to eight metres above its 20th century level.

The droughts of the mid-latitude continental interiors during the Mediaeval Warm Period agree with model projections for global warming. Warming may increase evaporation and hence rainfall at these latitudes in ocean-influenced climates, where ample water or vegetation surface is available for evaporation. But beyond the reach of this moisture, e.g. in the rain shadow of the Rockies, or anywhere inland where atmospheric high pressure cells predominate in summer, the effect can be progressive soil and atmospheric drying and thence escalating, self-sustaining drought. The history and prospect of continental interior droughts holds an important message for viticultural (and other) planning, should warming continue for whatever reason.

0.2 Natural causes of climate change

The combined roles of changes in the earth's elliptical orbit around the sun in a 100,000-year cycle, of pendulum-like swings in the tilt of its axis of revolution over a 40,000-year cycle, and for a circular wobble in its axis of revolution, in a 22,000 year cycle are now recognized as controlling multimillennial changes in the earth's climate such as the coming and going of the ice ages over the past million or so years. Together these form a highly predictive model of climate changes across that timescale, now know as the Milankovich Model after its proponent Milutin Milankovich.

0.3 Anthropogenic causes of climate change

It is now widely believed that the increasing addition to the atmosphere of combustion by-products from fossil fuels used in industrial and other human activities can influence, perhaps dominate, global climate change in the direction of warming.

Chief among them is carbon dioxide (CO_2). This assumes primary importance because of its rapid increase with growing worldwide industrialization. (Water vapour plays a much larger greenhouse role, but is not of direct anthropogenic origin. Its amount in the atmosphere varies with temperature changes whatever their cause). Other greenhouse gases will be mentioned only briefly; except where necessary we will here adopt the usual approach of considering them as part of an overall 'CO_2 equivalent'.

The warming effect of greenhouse gases stems from the fact that they are transparent to most incoming short-wave solar radiation, but to varying degrees opaque to outgoing long-wave radiation, but to varying degrees opaque to outgoing long-wave radiation from the relatively cool earth. Outgoing heat is absorbed and trapped in this way, mainly in the lower atmosphere, or troposphere; it warms that air layer, which in turn radiates some of the heat back to lower air and the earth's surface. As greenhouse gases increase, so must tropospheric and surface temperature rise until the resulting greater outgoing radiation establishes a new equilibrium. However these changes and the final equilibrium reached can be much influenced by positive and negative feedback processes.

0.3.1 Carbon dioxide and water vapour

The difference between the earth's average surface air temperature (288°K, or 15°C) and its effective heat emitting temperature as seen from space (255°K, or minus 18°C) is a measure of its total existing greenhouse effect, which is due principally to water vapour and (to a smaller extent) CO_2.

The proportion due to CO_2 is estimated at about 25% (Shine et al. 1990). These authors, Kiehl and Ramanathan (1983), Ramanathan et al. (1987) and Ramanathan (1988) give accounts of the physics involved.

Main interest lies in the marginal effects of additional CO_2, which has already risen from its pre-industrial level of about 280 parts per million (ppm) to 385 ppm in 2008. Its greenhouse effect is, however, not directly proportional to concentration. Pre- industrial levels already satured their greenhouse fubction almost completely, so that further increments have steeply diminishing effects. These are now accepted as being proportional to the base 10 logarithm of CO_2 concentration. That is, temperature rise would be the same for each successive doubling of CO_2.

Efforts to model temperature responses to past and potential rises in atmospheric CO_2 have a long scientific history, but those incorporated into credibly realistic climate systems are generally taken to date from the work of Manabe and Wetherald (1967, 1975). They estimated that a doubling of atmospheric CO_2, once its effects had come into equilibrium, would directly raise global average temperature by 1.3 °C. The resulting enhanced evaporation and rise in atmospheric water vapour would raise it a further 1.0 °C, a total of 2.3 °C. Several other authors around the same time produced still lower figures. But later review suggested a variety of shortcomings in their calculations or assumptions. Most estimates since have settled around a direct CO_2 (or CO_2-equivalent) doubling effect around 1.1 – 1.2 °C, e.g. Hansen et al. (1981); Lal and Ramanathan (1984); Ramanathan et al. (1987). With allowance for resulting extra water vapour, but no other feedbacks, this given a warming from doubled CO_2 that is generally accepted among modellers of a little over 2.0 °C. This in turn equates to an enchanced 'radiative forcing' at the earth's surface of about 4.0 watts per square metre (Wm^{-2}) (Hansen et al. 1981; Ramanathan et al. 1987).

0.3.2 Anthropogenic aerosols and other pollutants

Whereas the simple effects of greenhouse gases and water vapour on surface air temperatures are generally thought of as well understood, those of other emission from burning fossil (and other) fuels are far from being so. Chief among them is sulphur dioxide (SO_2), which forms sulphate aerosols that can persist in the lower atmosphere for up to a week of two. These produce cooling by scattering and reflecting away incoming sunlight, in the same way as stratospheric volcanic aerosols. It is also thought that as supplementary cloud condensation nuclei, they produce increased numbers of consequently lighter droplets, deferring their coalescence and fall as raindrops. This both prolongs the lifespan of clouds and makes them more reflective.

The idea that some other anthropogenic factor might be counteracting the warming due to CO_2, water vapour and other greenhouse gases came with a realization by researchers that the measured warming since the start of thermometer records was less than computer models predicted they should be. Some key papers developing and modifying the idea are those of Wigley (1989), Charlson et al. (1991, 1992), Kiehl and Briegleb (1993), Mitchell et al. (1995), Mitchell and Johns (1997) and Hansen et al. (1997). Charlson et al. (1992) estimated from physical principles that present sulphate aerosols could result in a globally averaged cooling that would at least substantially offset the warming caused by greenhouse gases. However, the later estimates were more conservative.

Identifying the real-life temperature effects of anthropogenic aerosols should in theory be simple, since their main production is concentrated in industrial areas, while their short lifespan means that action must mostly be within those areas or fairly close down-wind. Yet the literature yields surprisingly few studies on that point. The most relevant I have been able to find is that of Engardt and Rodhe (1993), which gave mixed results. They identified major sources of SO_2 emissions in central and eastern Europe and, to lesser degrees, eastern USA and eastern China. All three centres showed evidence of minor summer cooling over time (0.2-0.4 °C) relative to the rest of the Northern Hemispere, but in eastern China and eastern USA there was a greater (0.5-0.9 °C) relative warming in winter.

Finally, the role of tropospheric ozone pollution has to be considered. This occurs both from industrial pollution and, mainly in the tropics, from biomass burning (Kiehl et al. 1999). Ozone acts as a greenhouse gas in the troposphere by absorbing both shortwave and longwave radiations. As with aerosols the effects are localized because of ozone’s limited lifespan, and are also seasonal because the lifespan is temperature-dependent, being greatest in summer. Kiehl et al. estimate that global positive forcing by tropospheric ozone in summer approximately halves what would otherwise be a direct negative forcing by sulphate aerosols, from -0.76 Wm^{-2} to -0.40 Wm^{-2}.

A best overall conclusion seems to be that anthropogenic aerosols and ozone pollution, between them, can offset global greenhouse and natural warming by at most only a very small amount. They cannot account for the discrepancy between modelled and measured recent warming.

0.3.3 Land use effects

Changes in land use have hitherto featured little in global climatic studies, but evidence is now available that they can have significant impacts locally, regionally and perhaps globally. Either warming or cooling can result.

One of the best-studied cases is that of the Midwestern and eastern USA, as documented by Bonan (1997, 2001). Since the mid 19th century the Midwest has experienced almost total replacement of woodlands and prairie by cropland. Over that time measured mean temperatures have fallen and diurnal temperature ranges narrowed, a process that has continued well into the 20th century (Karl et al. 1984). Proffered explanations are two-fold. First, crops with their shiny leaves reflect away more light energy than the native vegetation. Second, their large biomasses and leaf areas in summer-early autumn cool the adjacent atmosphere by transpiring large amounts of water in this well-watered region. (Winter transpiration is small whatever the vegetation). The cooling is mostly in the daytime, hence a reduced diurnal range. In recent decades the bigger crops obtained through intensive fertilizer use, and in some cases irrigation, have doubtless enhanced the process further even after crop area has stabilized.

The opposite happens when tropical rainforests are cleared, as Couzin (1999) has reported. Burning these and replacing them with grassland greatly reduces transpiration and cooling. Cleared areas of the Amazon rainforest have experienced up to 30% less rainfall, and temperatures some 1°C higher, than in the surrounding forest. Similar changes have occurred in tropical and sub-Saharan Africa.

Comparable heating and drying occurs in summer-autumn with the clearing of trees and their replacement by annual crops in Mediterranean climates. The deep-rooted natural vegetation of these climates transpires right through the dry summer, whereas the dry residues from winter-spring crops do not transpire at all. As well as raising summer temperatures, both locally and in adjacent wooded and coastal areas subject to hot land winds, this may be expected to delay and reduce rainfall around the autumn break of the normal rainy season. Less ‘roughness’ of the land surface also reduces turbulence and uplift of potentially rain-bearing winds. Pitman et al. (2004) and Timbal and Arblaster (2006) attributed to the latter factor about half the major winter rainfall decline that occurred in south-western Australia following extensive land clearing that pecked in the 1960s. The other half they attributed to a poleward shift in the weather systems that accompanied worldwide warming from the mid 1970s to the 1990s.

Contrariwise, irrigation in arid regions brings about marked cooling. Couzin (1999) cited research at Colorado State University, Fort Collins, showing that extension of irrigated crops in the 1990s locally reduced July mean temperatures by as much as 2 °C. Combined with more cloud and rainfall, this allowed conifers to establish naturally on the Rockies' eastern slopes at significantly lower altitudes than before.

Since the mid 20th century a new scenario has started to develop. Clearing of temperate woodlands for agriculture has reached its practical limit, as has the exploitation of water resources for irrigation. Any increase in irrigation area comes mostly through using more water- efficient methods such as drip irrigation and, now increasingly, regulated deficit or partial rootzone drying techniques. The overall cooling effect of irrigation has thus also reached its limit. Indeed, cases have emerged where over-diversion of water for irrigation has led to desertification and warming down-stream, as in the case of the Aral Sea in the former USSR. At the same time forest clearing has rapidly increased in the tropics and sub-tropics, where clearing regularly results in warming.

All climate effects from land-use changes are now in the direction of warming. Their global impact cannot be estimated accurately, but could be very significant across low and middle latitudes.

0.4 Current Climate Change and Viticulture

0.4.1 Direct effects of rising CO_2

The responses of greenhouse crops to CO_2 levels up to 1,000 ppm shows that they retain at least some of the genetic capacities of their ancestors, most of which evolved in atmospheres much higher in CO_2 than exist now.

Hardie (2000) notes that present grapevine (Vitis) species evolved in the Cretaceous period, 136-65 million year ago, under atmospheric CO_2 concentrations thought to have been around 1,500 – 3,000 ppm. With such ancestry they could be expected to respond positively to current rises in the same way as other crops. They might also be able to recover adaptation to much higher concentrations through selection or breeding.

The cultivated grapevines also means they should respond with fewer of the limitations to which natural vegetation is subject. Proper training system counters any limiting nutrient deficits and ensures adequate canopy light exposure. Cropping and pruning, between them, guarantee a low carbon status at the start of the season, giving fullest scope to respond to higher CO_2 in both dry matter production and fruitfulness (spring temperatures allowing).

Theoretically, higher CO_2 should enable the vine to carry heaving crops while remaining in carbon balance, through this equation could be complex, depending on initial effects on fruitfulness balanced against later capacity to ripen the crop set. Also important in the equation is provision of enough surplus assimilate, after crop needs have been met, for continuing root growth through ripening. This is essential for the fullest expression of flavour and terroir characteristics in the wine.

One immediate future concern is berry nitrogen content. Higher atmospheric CO_2 may increase crop and sugar yield, but uptake of nitrogen (which moves readily to the roots) is limited primarily by supply and does not necessarily increase in proportion to extra root growth. Also, photosynthesis continues unabated through fruit ripening at a time when the soil is often drying out and nitrogen uptake impeded. Thus management to ensure adequate berry nitrogen content will probably become more important over time.

It is different for nutrients such as phosphate and most of the trace elements that are largely insoluble and immobile in the soil. Uptake of these is by immediate root-tip contact and chemical exchange with soil minerals, so foraging roots must be dense and their growth continuous for most effective uptake. Stronger root growth under higher CO_2 will in most cases satisfy the plant’s correspondingly higher nutrient need, assuming there to be no acute deficiencies.

It also follows that if mineral uptake from deep roots to the berries during ripening plays a key role in terroirs expression, as I have argued, then maintaining late deep root growth through moderate cropping and water management will remain as essential as ever for wine quality and terroirs expression.

The improving water use efficiency of vines under rising atmospheric CO_2 should improve the vine’s stress and growth balance in environments previously too dry and stressful, and thus help extend viticulture into environments with less risk of damaging rains during berry setting and ripening. There are probable limits to how far viticulture can extend into dry atmospheres without compromising quality for table wines. Rising atmospheric CO_2 concentrations may necessitate some rise in temperature for optimum vine performance. Greenhouse horticultural crops grown in atmospheres enriched to 700-900 ppm CO_2 need temperatures 2-4 °C higher than under normal atmospheres to achieve fully their enhanced yield and quality potentials. Further, the main requirement is for higher night temperatures.

Summing up, the evidence shows that rising atmospheric CO_2, in addition to raising vine potential, is probably: a) raising optimum temperatures, especially night temperatures, for vine function; b) improving tolerance of high temperature extremes; and c) improving vine drought tolerance and water use efficiency. Effects on cold hardiness are as yet uncertain but could be positive. Some nutrient requirements will probably rise.

0.4.2 Climate and recent viticultural history

20th century growing seasons generally may been cooler than in the previous centuries when each region’s dominant grape varieties became established. But while that may still be broadly true, a closer examination of the recent record suggests possible alternative reasons for some of the observations.

The first concerns the influence of diurnal temperature range. In climates or parts of the growing season cool enough to slow phonological development they are primarily night temperatures that limit. The logic of this, combined with observed vine phenology across climates and mesoclimates with differing diurnal temperature ranges, has made possible a temperature adjustment for diurnal range that significantly improves the fit of vine phenology to standard temperature records. Based on this adjustment we can estimate the contribution of diurnal range to vine phenology changes over time in the study by G.V. Jones and Davis (2000b) of Bordeaux vintages. These authors showed a progressive and relatively uniform advance of 13 days in harvest date between 1952 and 1997. By contrast the recorded Bordeaux growing season average mean temperatures (G.V. Jones et al. 2005) remained more or less constant between 1952 and 1980 and then rose steeply to 1999.

In some study of French viticultural climates, the average growing season diurnal range at Bordeaux airport narrowed by 1.06 °C between 1931-60 and 1973-93, while recorded average mean temperature increaded by 0.29 °C. part of both changes could have resulted from airport/urban warming. Accepting the figures at face value, the resulting predicted advances in harvest date between periods would be seven days, comprising three days due to narrowing diurnal range and four days from rising means. The total predicted advance (allowing for the inexact correspondence of dates) agrees well with the measures trend in maturities as recorded by Jones and Davis.

A puzzling aspect of the Jones and Davis results, which were based on phenological observations and vintage rating for 10-15 leading quality vineyards, is that across the whole 1952-1997 period the average harvest starting date was 2 October. Given a total trend to earliness of ‘nearly 13 days’, that suggests an average date of 8 October at the beginning and 26 September at the end.

Another study of recent viticultural climates requiring scrutiny is that of Petrie and Sadras (2008), which follows the phenology of three grape varieties (Chardonnay, Cabernet Sauvignon and Shiraz), as measured by date of reaching 21.8° Brix sugar content, date of harvest, and °Brix at harvest, in commercial cultivation across 18 regions of south-eastern Australia from 1993 to 2006. It raises some important questions of interpretation.

Using date of reaching 21.8° Brix as the main maturity measure, responses to temperature were gauged in two ways. The first was matching each region’s average maturity dates for given varieties against the average mean temperatures at their respective references recording sites, either for November over the experimental years, or for the warmest month from long-term records after Gladstones (1992). The second approach was to match progressive maturity dates to the time series of recorded temperatures through 1993-2006, using regression analysis.

The first approach gave unambiguous results. Based on 1993-2006 November average mean temperatures at the respective reference sites, maturity averaged over the three varieties was earlier by 6.56 ± 0.92 days per 1°C higher temperature. Using long-term average means for the hottest month, tha advance average 6.27 ± approximately 0.48 days per 1°C higher temperature.

0.4.3 Projecting future climates

The following discussion focuses speculatively on the decades up to 2050, as being a minimum period for useful planning of new vineyards.

0.4.3.1 Mean temperatures

Records exist of mean temperatures from direct thermometer measurement for the past 150 years, and more approximately from proxy evidence for some hundreds of years. A first approach to projecting future temperatures, then, is to see if any semblance of regularity exists in past fluctuations that could continue into the future (IPCC, 2007).

Some quasi- regularity can indeed by discerned over the past two centuries, with temperature fluctuations showing a periodicity of around 70 years from peak to peak or trough to trough. Thus warming from the Dalton Minimum of the early 19th century led to relative warmth in the 1860s and

1870s, followed by a trough centred around 1900-1910, a new peak about 1940 and a (mild) trough ending in the early to mid 1970s. warming that started suddenly in 1976 continued steeply to the turn of the millennium, after which land-recorded temperatures stayed more or less constant to 2006.

This last warm period appears to have been associated with both a warm phase of the Pacific Decadal Oscillation and a preponderance of El Nino events, and also with a solar maximum. It remains to be seen whether the sharp 2007-2008 cooling, which accompanied a La Nina, is the start of renewed long-term cooling. Solanki et al. (2004) suggest that, having lasted an unusually long 65 years to that date, the 20th century solar maximum was unlikely to last much longer. In any event the pattern of the last 200 years points to a possible cool phase starting soon and potentially lasting to mid century.

Against such projections must be balanced any underlying, and by its nature progressive, warming by greenhouse gases. This is unlikely to be more than 0.4-0.5 °C for an effective doubling of concentrations. It could be less. A tentative conclusion, then, is that global mean temperatures and their variation up to the mid 21st century will not differ much from those of the late 20th century. Beyond mid 21st century a continuation of the same patterns could see renewed modest warming starting about then and continuing to the end of the century.

0.4.4 Implications for vine terroirs

Recent concerns for future viticulture and its terroirs have focused almost entirely on climate change, and in particular, greenhouse warming.

Terroirs expression should be minimally affected, given that it is remarkably robust across short-term climate fluctuations that occur naturally from season to season and decade to decade.

That is how terroir came to be recognized and defined, demostrating how much of it depends on unchanging local features of geography, topography, soil and underlying geology.

Any warming will certainly allow spread of viticulture polewards and to higher altitudes, and such vineyards may be needed to maintain some cool-climate wine styles in their purest forms. These vines will, however, be least able to exploit the higher CO_2 available to them. Hot and dry inland viticultural areas, through suffering disproportionate heating and drying, may compensate through the vines' greater water use efficiency and heat tolerance. But effects on wine quality will probably be adverse.

A practical conclusion is that past experience will continue to provide a valid guide to viticultural climates and terroirs for at least some decades to come. Climate tables based on the mid to late 20th century, and calibrated against observed vine phenology for that period, will remain directly relevant.

0.5 Effects of climate change in Campania (Southern Italy)

In order to estimate the influence of global climate change in the region of Campania (southern Italy), Ducci and Tranfaglia (2008) had studied variations in the water budget prompted by precipitation and temperature changes. In many parts of the region, precipitation distribution in the last decades shows a marked reduction. During the same period, Campania also experienced a regional temperature increase of about 0.3°C. Water budgets, calculated in a geographical information system environment for the region's hydrogeological structures, show a mean decrease of 30% of average infiltration within the present climate scenario. The most severely affected zones are the mountainous areas in the southern and northern parts of Campania (Diodato et al. 2011).

0.5.1 Climatic characteristics of Campania

The region of Campania has a Mediterranean climate, affected by the Azores, Siberian and South African anticyclones and the Aleutian and Icelandic lows, with hot, dry summers and moderately cool rainy winters. Mean annual temperatures are in the range of about 10. 8° C in the mountainous interior, 18.8 °C in the coastal areas, and 15.58 °C in the plains surrounded by the carbonate massifs. In Campania the correlation between temperature and elevation is extremely high (generally 0.9), with a gradient of about 20.58 °C to 20.78 °C each 100 m. The Italian rainfall regime consists of four different types: (1) Alpine continental; (2) Alpine sublittoral; (3) Apennine sublittoral; and (4) Marine. The rainfall regime in Campania is Apennine sublittoral, with a maximum in autumn/winter. Precipitation is influenced mainly by the mountain chains, in terms of elevation (often 1500–2000 m a.s.l.), location of ridges (barrier effect) and proximity to the Tyrrhenian Sea. The lowest mean annual rainfall, about 700 mm, occurs in the eastern part of the region, on the other side of the Apennine watershed; the highest, about 1800 mm, occurs in the central part of the Apennine ridge (Ducci et al. 2005)

0.5.2 Climate change analysis in Campania

Climatic phenomena are often the product of two or more, simple, interacting non-linear processes. As a result, chaotic processes in the atmosphere are extremely sensitive to small disturbances. Small variations in atmospheric turbulence can result in very different outcomes and then it becomes impossible either to measure the system accurately or to predict its future state (Bryant 1997). The actual atmospheric phenomena taking place over an area are the final stage of a number of different processes occurring on different scales, therefore the estimation of the areal distribution of meteorological parameters from point observations has been, and probably will remain, one of the most difficult issues within geophysics. The occurrence of intense flooding causing landslides in autumn and winter in Campania depends on small cyclonic areas, the dynamics of which follow the genesis of tropical cyclones (hurricanes), but show a low level of energy (Tranfaglia & Braca 2004). Such meteorological systems, together with convective systems and orographic rainfall, can be intensified by the higher contribution of heat at the sea surface and often cause sudden flooding in coastal regions and in mountain regions exposed to sea winds. A major challenge to climate researchers is to determine the degree of predictability associated with these and other events. The analysis of historical series of rainfall recorded in four large Italian watersheds shows that more than 50% of their interannual variance is significantly explained by the 22-year harmonics. It is proposed by Mazzarella et al. (2003) that the 22-year solar magnetic activity is able to influence the zonal circulation over the Mediterranean basin and the relative rainfall. Mazzarella & Tranfaglia (2000) investigated the capability of the historical rain gauge network belonging to the Naples Hydrographic Service to measure the annual rainfall in Campania. They found that the value of the fractal dimension D was equal to 1.84, with a confidence level higher than 99%, within a scaling region enclosed between 8 km and 64 km with a dimensional deficit equal to 0.16 (2–1.84). A 50% lower limit value of the scaling region (4 km) represents the optimal value of the network resolution.

The temperature variability was observed by comparing the 48 yearly raster maps of the temperature (1951–1999, excluding the year 1991 with only two stations working). The temperature maps highlight the differences between areas

according to elevation: the higher increases in temperature are in mountainous areas and the lower in the coastal plains. Statistical comparison between the 48 maps allowed its to detect the differences between the period 1951–1980 and the warmer period 1981–1999. Figures 1a and b show the mean annual temperature maps for the years 1951–1980 and 1981–1999, respectively.

The analysis of temperatures demonstrates a clear increase, of an average of 0.3 °C (from 0.2 °C in coastal flat areas to 0.5 °C in mountainous areas). These trends are in agreement with the results of the UK Hadley Centre global climate model, running on monthly climatic data from Mediterranean countries (i.e. HadCM2 in De Wrachien et al. 2002). In the southern Mediterranean, this model indicates a rainfall decrease of about 10–15% and a temperature increase of 1.5–2.58 C° by the year 2050.

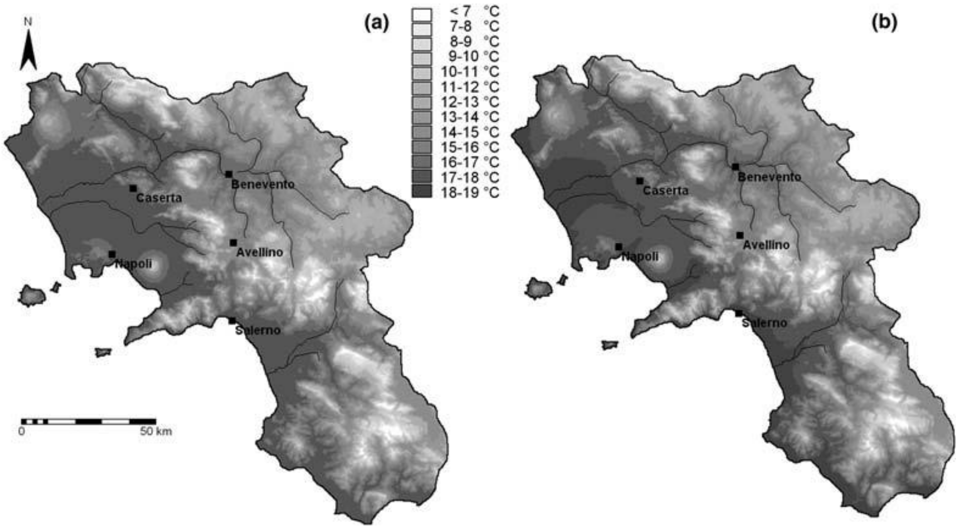

Figure 1 - Mean annual temperature maps (in °C) for 1951–1980 (a) and 1981–1999 (b). From Ducci et al. 2008.

Figures 2 and 3 show the mean annual rainfall maps for the years 1951–1980 and 1981–1999, respectively. The rainfall maps were obtained by the average of the annual DRM raster maps for 30 years and 19 years, respectively. The rainfall maps constructed according to this method differ markedly in some sectors from the average rainfall maps obtained by interpolation of mean annual data. For the whole region, the annual volume of rainfall is 16,000 mm^3 for the period 1951 to 1980, and 13,500 mm^3 for the period 1981–1999, with a decrease of about 15% (Fig. 4).

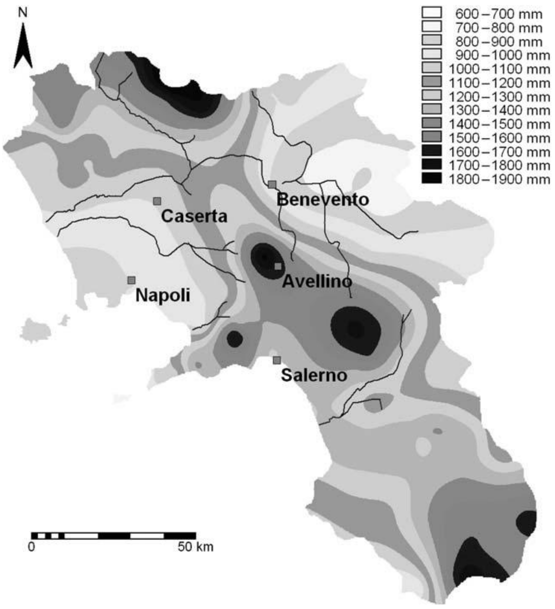

Figure 2 - Mean annual rainfall map (mm/a) for the years 1951–1980. From Ducci et al. 2008.

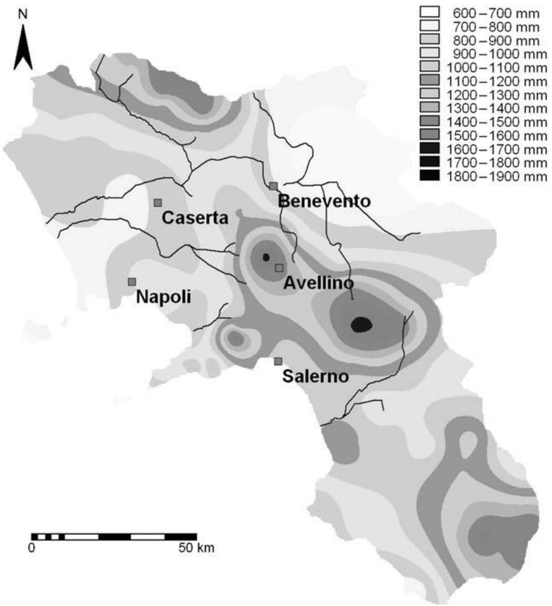

Figure 3 - Mean annual rainfull map (mm/a) for the years 1981–1999. From Ducci et al. 2008.

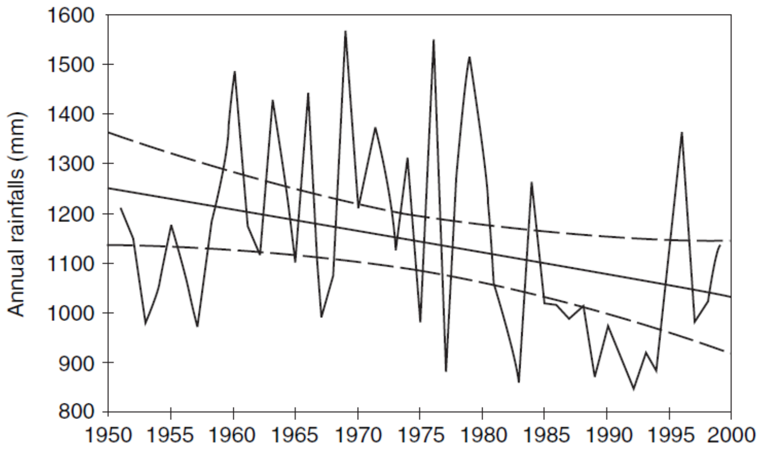

Figure 4 - Mean annual rainfall in Campania (1951–1999) with confidence bands for mean. From Ducci et al. 2008.

Finally, we can affirm that in Campania in the last decades, the precipitations distribution shows reduction in rainfall, and a mean regional temperature increase (0.2–0.58 °C). The rise in temperature and decrease in precipitation have had a sequence of direct effects on the hydrological cycle, with particular regard to the evapotranspiration rate, soil moisture, surface runoff, and finally groundwater recharge (Ducci et al. 2008; Diodato et al. 2011; Diodato et al. 2014).

0.6 References

Bonan, G. B. (1997). Effects of land use on the climate of the United States.*Climatic Change*, *37*(3), 449-486.

Bonan, G. B. (2001). Observational evidence for reduction of daily maximum temperature by croplands in the Midwest United States. *Journal of Climate*,*14*(11), 2430-2442.

Bradley, R. S. (1991). Pre-instrumental climate: how has climate varied during the past 500 years. *Greenhousegas-induced climatic change: a critical appraisal of simulations and observations. Elsevier, Amsterdam*, 391-410.

Bryant, E. (1997). Climate Process and Change. Cambridge University Press, Cambridge.

Charlson, R. J., Langner, J., Rodhe, H., Leovy, C. B., & Warren, S. G. (1991). Perturbation of the northern hemisphere radiative balance by backscattering from anthropogenic sulfate aerosols*.*Tellus A*, *43*(4), 152-163.

Charlson, R. J., Schwartz, S. E., Hales, J. M., Cess, R. D., COAKLEY, J. J., Hansen, J. E., & Hofmann, D. J. (1992). Climate forcing by anthropogenic aerosols. *Science*, *255*(5043), 423-430.

Cook, E. R., Palmer, J. G., & D'Arrigo, R. D. (2002). Evidence for a 'Medieval Warm Period'in a 1,100 year tree-ring reconstruction of past austral summer temperatures in New Zealand. *Geophysical Research Letters*, *29* (14), 12-1.

Cook, E. R., Woodhouse, C. A., Eakin, C. M., Meko, D. M., & Stahle, D. W. (2004). Long-term aridity changes in the western United States. Science, 306 (5698), 1015-1018.

Couzin, J. (1999). Landscape changes make regional climate run hot and cold.*Science*, *283*(5400), 317-319.

De Wrachien, D., Ragab, R., & Giordano, A. (2002). Environmental Impacts of Climate Change in the Mediterranean: EC Actions to Mitigate Drought and Prevent Desertification. In *2nd International Conference on New Trends in Water and Environmental Engineering for Safety and Life: Eco-compatible Solutions for Aquatic Environments* (pp. 50-51). Essestampa srl.

Diodato, N., Chirico, G. B., & Romano, N. (2014). Monthly Erosive Storm Hazard Within River Basins of the Campania Region, Southern Italy. In*Storminess and Environmental Change* (pp. 117-129). Springer Netherlands.

Diodato, N., Bellocchi, G., Romano, N., & Chirico, G. B. (2011). How the aggressiveness of rainfalls in the Mediterranean lands is enhanced by climate change. *Climatic change*, *108*(3), 591-599.

Ducci, D., & Tranfaglia, G. (2008). Effects of climate change on groundwater resources in Campania (southern Italy). *Geological Society, London, Special Publications*, *288* (1), 25-38.

Ducci, D., Tranfaglia, G., & Applicata, D. I. G. S. G. (2005). L'impatto dei cambiamenti climatici sulle risorse idriche sotterranee della Campania. *Geologi (Boll Ordine Geologi Della Campania)*, 1-4.

Engardt, M., & Rodhe, H. (1993). A comparison between patterns of temperature trends and sulfate aerosol pollution. *Geophysical research letters*,*20* (2), 117-120.

Esper, J., Cook, E. R., & Schweingruber, F. H. (2002). Low-frequency signals in long tree-ring chronologies for reconstructing past temperature variability.*science*, *295*(5563), 2250-2253.

Fairbridge, R. W. (1962). *World sea-level and climatic changes*.

Gladstones, J. (1992). *Viticulture and environment*. Winetitles.

Gladstones, J. (2011). *Wine, terroir and climate change*. Wakefield Press.

Gornitz, V., Lebedeff, S., & Hansen, J. (1982). Global sea level trend in the past century. *Science*, *215*(4540), 1611-1614.

Hansen, J., Johnson, D., Lacis, A., Lebedeff, S., Lee, P., Rind, D., & Russell, G. (1981). Climate impact of increasing atmospheric carbon dioxide. *Science*, *213*(4511), 957-966.

Hansen, J., Sato, M., Lacis, A., & Ruedy, R. (1997). The missing climate forcing. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *352*(1350), 231-240.

HARDIE, W. (2000). Grapevine biology and adaptation to viticulture. *Australian Journal of Grape and Wine Research*, *6*(2), 74-81.

Jones, G. V. (2005). Climate change in the Western United States grape growing regions. *Acta horticulturae 689, 41-59.*

Jones, G. V., & Davis, R. E. (2000b). Climate influences on grapevine phenology, grape composition, and wine production and quality for Bordeaux, France. *American Journal of Enology and Viticulture*, *51*(3), 249-261.

Jones, P. D., & Mann, M. E. (2004). Climate over past millennia. *Reviews of Geophysics*, *42*(2).

Karl, T. R., Kukla, G., & Gavin, J. (1984). Decreasing diurnal temperature range in the United States and Canada from 1941 through 1980. *Journal of climate and applied meteorology*, *23*(11), 1489-1504.

Kiehl, J. T., & Briegleb, B. P. (1993). The relative roles of sulfate aerosols and greenhouse gases in climate forcing. *Science*, *260*(5106), 311-314.

Kiehl, J. T., & Ramanathan, V. (1983). CO2 radiative parameterization used in climate models: Comparison with narrow band models and with laboratory data.*Journal of Geophysical Research: Oceans (1978–2012)*, *88*(C9), 5191-5202.

Kiehl, J. T., Schneider, T. L., Portmann, R. W., & Solomon, S. (1999). Climate forcing due to tropospheric and stratospheric ozone. *Journal of Geophysical Research: Atmospheres (1984–2012)*, *104*(D24), 31239-31254.

Laird, K. R., Fritz, S. C., Maasch, K. A., & Cumming, B. F. (1996). Greater drought intensity and frequency before AD 1200 in the Northern Great Plains, USA.

Lal, M., & Ramanathan, V. (1984). The effects of moist convection and water vapor radiative processes on climate sensitivity. *Journal of the atmospheric sciences*, *41*(14), 2238-2249.

Lamb, H. H. (1977). *Climate: Present, Past and Future: Volume 2: Climatic History and the Future*. Methuen, London.

Lamb, H. H. (1982). *Climate, history and the modern world*. Methuen, London.

Lamb, H. H. (1984). Climate in the last thousand years: natural climatic fluctuations and change. *The climate of Europe: past, present and future*, 25-64.

Le Roy Ladurie, E. (1971). Times of feast, times of famine.

Manabe, S., & WETIIERALD, R. T. (1967). Thermal equilibrium of the atmosphere with a given distribution of relative humidity.

Manabe, S., & Wetherald, R. T. (1975). The effects of doubling the CO2 concentration on the climate of a general circulation modell.

Mazzarella, A. & Tranfaglia, G. (2000). Fractal characterization of geophysical measuring networks and its implication for an optimal location of additional stations: an application to a rain-gauge network. Theoretical and Applied Climatology, 65, 157–163.

Mazzarella, A., Di Cristo, R., Tranfaglia, G. & Viola, R. (2003). La modulazione magnetica della pioggia in Italia. Bollettino Geofisico (AGI), 26 (3–4), 25–34.

Mitchell, J. F. B., & Johns, T. C. (1997). On modification of global warming by sulfate aerosols. *Journal of climate*, *10*(2), 245-267.

Mitchell, J. F. B., Davis, R. A., Ingram, W. J., & Senior, C. A. (1995). On surface temperature, greenhouse gases, and aerosols: Models and observations. *Journal of Climate*, *8*(10), 2364-2386.

Oerlemans, J. (2005). Extracting a climate signal from 169 glacier records.*Science*, *308*(5722), 675-677.

Osborn, T. J., & Briffa, K. R. (2004). The real color of climate change. *Science*, *306* (5296), 621-622.

Petrie, P. R., & Sadras, V. O. (2008). Advancement of grapevine maturity in Australia between 1993 and 2006: putative causes, magnitude of trends and viticultural consequences. *Australian Journal of Grape and Wine Research*, *14*(1), 33-45.

Pfister, C. (1984). Klimageschichte der Schweiz 1525-1860. Das Klima der Schweiz und seine Bedeutung in der Geschichte von Bevölkerung und Landwirtschaft. *Verlag Paul Haupt Bern*.

Pfister, C. (1988). *Variations in the spring-summer climate of central Europe from the High Middle Ages to 1850* (pp. 57-82). Springer Berlin Heidelberg.

Pitman, A. J., Narisma, G. T., Pielke, R. A., & Holbrook, N. J. (2004). Impact of land cover change on the climate of southwest Western Australia. *Journal of Geophysical Research: Atmospheres (1984–2012)*, *109*(D18).

Ramanathan, V. (1988). The greenhouse theory of climate change: a test by an inadvertent global experiment. *Science*, *240*(4850), 293-299.

Ramanathan, V., Callis, L., Cess, R., Hansen, J., Isaksen, I., Kuhn, W., & Schlesinger, M. (1987). Climate-chemical interactions and effects of changing atmospheric trace gases. *Reviews of Geophysics*, *25*(7), 1441-1482.

Röthlisberger, F., & Geyh, M. A. (1986). *10000 [Zehntausend] Jahre Gletschergeschichte der Erde: Teil I: e. Vgl. zwischen Nord-u. Südhemisphäre; Alpen-Skandinavien-Himalaya-Alaska-Südamerika-Neuseeland. Teil 2: mit e. Beitr. 14C-Daten zu Gletscherständen-Probleme der Deutung*. Sauerländer.

Schove, D. J. (1955). The sunspot cycle, 649 BC to AD 2000. *Journal of Geophysical Research*, *60*(2), 127-146.

Shine, K. P., Derwent, R. G., Wuebbles, D. J., & Morcrette, J. J. (1990). Radiative forcing of climate. *Climate Change: The IPCC Scientific Assessment*, 41-68.

Solanki, S. K., Usoskin, I. G., Kromer, B., Schüssler, M., & Beer, J. (2004). Unusual activity of the Sun during recent decades compared to the previous 11,000 years. *Nature*, *431*(7012), 1084-1087.

Stine, S. (1994). Extreme and persistent drought in California and Patagonia during mediaeval time. *Nature*, *369*(6481), 546-549.

Thompson, L. G., Mosley-Thompson, E., Dansgaard, W., & Grootes, P. M. (1986). The Little Ice Age as recorded in the stratigraphy of the tropical Quelccaya ice cap. *Science*, *234*(4774), 361-364.

Timbal, B., & Arblaster, J. M. (2006). Land cover change as an additional forcing to explain the rainfall decline in the south west of Australia.*Geophysical Research Letters*, *33*(7).

Tranfaglia, G. & Braca, G. (2004). Analisi idrologica e meteorologica dell’evento alluvionale del 25–26 ottobre 1954: confronto con le serie storiche evalutazione del periodo di ritorno di eventi analoghi. In: ESPOSITO, E., PORFIDO, S. & VIOLANTE, C. (eds) Il nubifragio dell’ottobre 1954 a Vietri sul Mare. Costa di Amalfi, Salerno. CNR-GNDCI-IAMC, 295–348.

Wigley, T. M. L. (1989). Possible climate change due to SO2-derived cloud condensation nuclei.

Wigley, T. M., Kelly, P. M., Eddy, J. A., Berger, A., & Renfrew, A. C. (1990). Holocene Climatic Change, $^{14} $ C Wiggles and Variations in Solar Irradiance [and Discussion]. *Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences*, *330*(1615), 547-560.

Woodhouse, C. A., & Overpeck, J. T. (1998). 2000 years of drought variability in the central

United States. *Bulletin of the American Meteorological Society*,*79*(12), 2693-2714.

Yang, B., Braeuning, A., Johnson, K. R., & Yafeng, S. (2002). General characteristics of temperature variation in China during the last two millennia.*Geophysical Research Letters*, *29*(9), 38-1.

1 STATE OF THE ART

The acceleration of ripening in wine grapes has been extensively documented worldwide (Jones et al. 2005). An increase in carbon dioxide emissions and other greenhouse gases are altering the composition of the atmosphere. It is likely that most of the global warming since the mid-20th century has been due to increases in greenhouse gases from human activities (Intergovernmental Panel on Climate Change 2007). By 2050 the projected increase in annual average temperature in grape-growing regions is estimated to range from 0.4 to 2.6°C (Webb 2006). Increases in annual average temperature between the present day and the year 2030 are expected to range from 0.2 to 1.1°C in many of the Australian grape-growing regions. A steady trend of increased warming is pushing traditional areas of grapegrowing toward accelerated ripening (Jones et al. 2005), leading, in turn, to excessive sugar accumulation in the fruit and high alcohol in the wine.

Wine consumer preferences over the last decade are changing (Schultz 2000; Jones et al. 2005) towards lower alcohol wines. The growing demand for wines with moderate alcohol content is leading to a reappraisal of current production systems as well as management techniques. Canopy management practices are able to stabilize or slow maturation Palliotti et al. (2012), grapevine phenology is predominantly temperature-driven (Jones and Davis 2000; Pearce and Coombe 2004). Matching the critical developmental stages of grapevines to a suitable climate is a fundamental factor in the planning of new vineyards where optimising quality is a priority. Mcintyre et al. (1982) describe the timing of phenology in many grape varieties and the possibility of a ‘best fit’ variety for a particular climate. In a future climate change scenario, rising temperature may change the timing of grape ripening and consequent harvest date, and may affect grape quality and yield (Haselgrove et al. 2000; Marais 2001; Marais et al. 2001; Spayd et al. 2002; Webb 2006). Therefore the projected temperature increases could have a major impact on such phenological events in terms of both winegrape production and quality across wine regions, especially as grapevine phenology varies with regions and varieties (Smart et al. 1980). The impact in question could be positive or negative depending on the present climate of the region (Dry 1988). Since Australia's climate can vary greatly from one year to the next, temperature increases will have varying levels of impact in different regions at different times of year.

The alcohol content of wines is reported to be increasing worldwide. In Australia, during the period 1984-2004, the alcohol content rose from 12.3% to 13.9 % in red wines and from 12.2% to 13.2 %

in whites (Godden and Gishen 2005). Dokoozlian (2009) reports that the average sugar content of Cabernet Sauvignon musts increased from 21-22° Brix in 1990 to 24-25° Brix in 2008 in the Napa Valley. This finding was supported by Vierra (2004), who found that the average alcohol content of Napa Valley wine increased from 12.5 % to 14.8 % during the period 1971 to 2001. Duchene and Schneider (2005) also report that the alcohol potential of Riesling produced in Alsace increased by 2.5% over the last 30 years due to higher temperatures during ripening. Although all changes in the phenological development have been well documented, perhaps the most striking is the advance of harvest time by more than a month. Ganichot (2002) compared harvest dates from 1945 to 2005 in Chateauneuf du Pape (France) and found that harvest time was getting early; advancing from early October in 1945to early September in 2000. In recent years, the harvest date of Montepulciano grown in Abruzzo, advanced by 14-15 days, in the central part of the region and 10 days when grown closer to the coast (Di Lena et al. 2010).

As a mean to reduce sugar accumulation, numerous studies have considered agronomic practices that limit photosynthetic activity and increased competition between sink and source. The use of commercial products that reduce the transpiration rate and hence photosynthesis induce a variation in the metabolism of carbohydrate compounds and their translocation in the berries (Palliotti et al. 2012; Carnevali and Falcetti 2012; Lazzini et al. 2012; Tittmann et al. 2013).

1.1 Traditional and innovative cultivation techniques, applicable to slow the technological grape maturation

It is useful to reconsider potential applications of some traditional and innovative cultivation techniques able to regularize or even delaying ripening too accelerated and / or unbalanced. According to their mode of action, this cultivation techniques can be classified into four groups.

1.1.2 Cultivation techniques based on the mechanisms induction of nutritional competition between wine organs

Calibrated increase of unitary productivity achieved increasing the buds number

Conditions of high unitary productivity are generally accompanied by a low ratio between the "leaf surface" and "production " (less than 0.8 and 0.5 m^2/kg respectively for the vertical and horizontal grape training systems), and involve a limitation in the capacity of accumulation of sugars in the berry (Kliewer and Dokoozlian, 2005). In these situations it is possible to speed up and improve the maturation course increasing the ratio "leaf area/grapes" using a load containment production, which can be obtained by a bunch thinning (Fig. 5) (Palliotti and Cartechini, 1998; Palliotti et al. 2008c) or by an early sprout suppression (Bernizzoni et al. 2011).

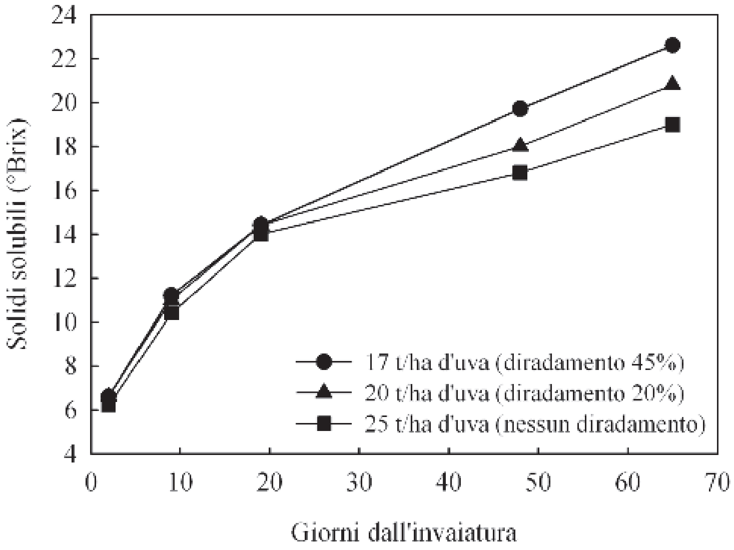

Figure 5 - Seasonal evolution of soluble solids accumulation in vineyards of Montepulciano trained to “tendone” system with different crop load in Abruzzo region. Different bunch thinning (BT): 17 t/ha of production with 45% BT, 20 t/ha of production with 20% BT and 25 t/ha of production without BT. From Palliotti et al., 2012.

Conversely, we can not affirm with equal certainty that we can diminish the capacity of sugar accumulation in grapes only by an increase in buds number in pruning winter, especially in balanced and well managed vineyards. In these cases, in fact, besides the vintage effect, also the nutritional reserves accumulated in the wood and in the roots can play a significant role (buffer effect). For example, in 2011 year, an increase of bud load from 43,400 to 78,700 per hectare (precisely 9 *vs* 16.3 buds/vine) in a Sagrantino vineyard managed to cordon has not induced substantial changes on the sugars accumulation and organic acids degradation in must, despite an increase in plants productivity of 64% and a concomitant decrease of phenolic component of the grapes, precisely -17% for anthocyanins and -35% for total polyphenols (Palliotti et al. 2012).

Topping of the shoots and late irrigation

Another possibility on which base a strategy of slowing maturation is to exploit the normal relationships of growth competition between shoots and bunches. Figure 6 shows the ideals trends of the two processes; the curve of the speed of shoots growth slows after flowering and stops at veraison, when begins the berry growth that proceeds regularly according to the well-known trend double sigmoid. The ideal term, with which we have just defined these developments, it is justified by the dynamics of the two curves satisfies a specific physiological criterion of viticulture: for privileging maturation processes, there should be no competitive relationship between the two phenomena which, in fact, temporally do not overlap. It is evident that the changing of climatic conditions and then of the potential maturation leads to re-interpret these relationships assuming that a shifting right of the growth shoots curve may trigger a mechanism of vegetative competition that it would be useful to slow down the ripening. In this respect, the practical problem is how to induce, for example, a regrowth of “femminelle”. We have two most reliable techniques: the first one is using the time and the severity shoots topping to stimulate the production of “femminelle”. In the specific case the interest would be the development of “femminelle” able to perform a function more competitive, through shoots topping more late and/or severe. The second refers to an use of the water resources. A delayed irrigation could be used to revive vegetative growth in the final part of the season leaving some apex of the young “femminella” for slow the process of berries sugar accumulation. Late irrigation could cause a dilution of the must and decreasing the concentration of the sugars and organic acids. As regards the technique of topping of the shoots, Stoll et al. (2010) with interventions in allegation time have obtained a delay of Riesling maturation of about 20 days and a significant reduction of sugars accumulation capacity in the must by more than 4 ° Brix, while Filippetti et al. (2011), following a late topping performed one week after veraison, led on Sangiovese a significant reduction in the accumulation of the sugars in the must without changing the pH and the organic acids content, anthocyanins and tannins in seeds and skins. Even in Spain, on Grenache and Tempranillo, summer pruning particularly "Aggressive" (cut made, after fruit set, immediately above the distal cluster), have reduced the relationship "leaf area / grape" and, at the same time, slowed the ripening process with significant decreases of sugar content, anthocyanins and total polyphenols and the pH in the must, as well as the weight of the bunch and the berry (Balda and Martinez de Toda, 2011). Older surveys performed in Umbria on different black and white berry vines showed as summer pruning performed too late, ie five weeks after full bloom, contrary those early, applied a week after flowering, determine slowdowns in the sugars accumulation and in the organic acids degradation (Palliotti, 1992; Cartechini et al. 1998). Independently of the grape and the year, these results are mainly due to two effects: reduction of the ratio "Leaf area / grape" and nutritional competition between the development of neo femminelle formation and the accumulation phase in grapes. The results expected from the late topping buds are tightly bound, as well as the time and intensity of assistance, including the vigor of the site of cultivation and environmental factors, rains in the first place, which can promote the late development of femminelle and / or a put off of berries increase essential to obtain that nutrition competition necessary to induce a slowdown of the processes of maturation grapes, including the must sugars accumulation.

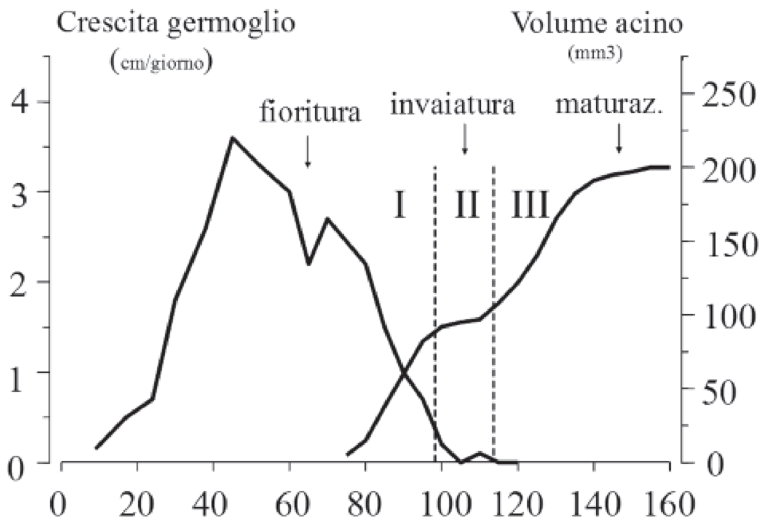

Figure 6 - Seasonal evolution of shoot and berry growth. From Palliotti et al. 2012.

Late winter pruning

Recently it has been deferred that also the period of pruning can slow the course of grapes maturation; Friend and Trought (2007) in fact of Merlot bred in New Zealand have shown that the winter pruning performed late or very late: 1, 2 or 3 months after the usual application date of this practice, can decrease grapes soluble solids concentration (up to -3.6 °Brix), slow down the degradation of organic acids and maintain an optimum must pH value.

1.1.3 Cultivation techniques based on the induction of calibrated stress photosynthetic

Later leaf removal, canopy shading and use of substances with antitraspirant activity

It is known that the leaves of about 40-50 days are most efficient and that, after this limit, begins a continuous and gradual functionality decline (Palliotti and Silvestroni, 2004; Poni et al. 2007). On this basis, it is evident that, from veraison forward, the most important leaves for the grapes maturation are those located in the middle portion and apical bud. Therefore, if the purpose is to slow the grapes ripening, a possibility would be to induce a photosynthetic calibrated stress, performing a mechanical defoliation rather late, in post-veraison, concentrated on the upper part of the canopy (Fig. 6). This technique applied on 23 August 2011 in a Sangiovese vineyard manged to cordon with planting distances of 2.5 × 0.8 m (5,000 plants/ha) using a mechanical leaf remover Binger (Seilzug GmbH & Co., Germany) in the top portion of the canopy, with two steps for each row, has determined a slowdown in the sugars accumulation capacity in the must (Palliotti et al., 2013). Elimination of 36% of the unit leaf area (equal to 2.6 m^2/vine) is corresponded a reduction in the "leaf area/grape" of 52% (0.99 m^2/kg), and of must sugar as 1.1 °Brix, without penalizing the other compositional parameters is the grape and in the wine. In the defoliation-harvest interval, in defoliated thesis was found a rate of must sugars accumulation as 0.19 °Brix/day *vs* 0.23 °Brix/day in control thesis. In a recent paper, Stoll et al. (2010) have obtained, of Riesling, a maturation delayed about two weeks following mechanics defoliation performed during fruit set in part above the bunches with the removal about 43% of the total leaf area.

However, not necessarily the imposition of a photosynthetic stress must pass through the leaves removal; can, in fact, be used shading techniques total or in part canopy by, for example, neutral networks shielding also useful in the case of particular oenological products. Specifically, a shading limited at the end of the bunches certainly helps in containing overheating of the grapes and then in preserving a higher proportion of malic acid, essential component in a perspective of winemaking for white wines, including sparkling and / or sparkling base. In this regard, studies performed on light stress deficiency (Cartechini and Palliotti, 1995) have put highlight how the artificial canopy shading of Sangiovese made putting, before bud burst, neutral networks shielding able to mitigate the 40% and 70% of the full light solar, have reduced significantly the photosynthetic activity of the leaves during the day with a negative impact on unitary productivity (-11% and -14% respectively in the thesis screen 40% and 70% compared to the control developed to full sunlight), the accumulation of sugars in must (respectively -4.3 and -5.1 °Brix) and organic acids degradation, with more acid grapes in shade canopy.However, a slowdown in the maturation of the grapes was found as a result of artificial shading in many varieties and environments (Bureau et al. 2000; Downey et al. 2004; Scafidi et al. 2013). Certainly, the last frontier with regard to mode with which to induce a calibrated photosynthesis drop is the application, in the entire or part of canopy sectors, of antitraspirant products of natural origin obtained by distillation from resins of conifers. Surveys conducted since 2008, with late applications in post-veraison of antitraspirant showed a constant and significant reduction of must sugar accumulation, alcohol content in the wine and a slowdown grapes ripening independently of the year, of cultivars and of production in study carried out in Central Italy (Palliotti et al. 2011b). Furthermore, in grapes of the thesis treated with the antitraspirant, was observed a decrease in the levels of anthocyanins in grapes variable depending on the grape variety and vintage production load, up to a maximum of -28% detected in Sangiovese managed with a production very high, more than 30 t/ha of grapes. Total polyphenols is less affected after antitraspirant treatment compared to anthocyanins, especially in red grapes. The phenolic compounds reduction found after antitraspirant treatment, certainly not very desirable in red wines especially for aging, could be acceptable instead wine ready to drink, rosé or for base wines for blending with other more rich in color and polyphenols. In white grapes, instead, the antitraspirant applied belatedly, in addition to ensuring a reduction of the must sugar content and then alcohol content of the wines, has also achieved a reduction of the component phenolic, with undoubted advantages in terms of minor instability, even chromatic, and transmission notes perceptible bitter, hardly balanced by other components of the wine. Another interesting aspect of this approach with antitraspirants products is that the transpiration and stomatal conductance are limited more than proportionally the net photosynthesis thus making the leaves more efficient. In fact, like that found in previous searches performed with antitraspirants applied in pre-flowering (Palliotti et al. 2010), also the late applications, independently of the production, they did find water use efficiency values significantly higher in the leaves of the treated theses. In fact, the decrease in net photosynthesis, varying from -25% to -33%, was less than proportional to decrease in stomatal conductance, which is varied instead from a minimum of 33% to a maximum of 43%.

1.1.4 Cultivation techniques based on the use of products that act on the ripening processes

Treatments with synthesis auxin, brassinazolo, salicylic acid and synthesis cytokinins

Among the innovative technical there is the use of different regulators plant growth. The use in pre-veraison of naphthalenacetic acid (NAA) at a concentration of 50 mg/l of bunches of Shiraz has shown that the maturation grape, in addition to being more synchronous inside the same bunches, was delayed about 10 days without altering the sugar content and the anthocyanins content (Böttcher et al. 2010). In fact already in 1997, always on Shiraz, Davies et al. obtained a delay the ripening of the grapes of two weeks as a result of immersion of the bunches for 30 seconds in acid benzothiazole-2-ossacetico (BTOA) at 6 and 8 weeks after flowering. The bunches treated showed a delay in the increase berry weight, in the anthocyanins accumulation, in deformability, in the hexose concentration and in the level of abscisic acid. Same authors affirmed that auxins, in association with abscisic acid, may act directly on the expression of genes involved in the ripening process. Among the hormones that stimulate the berry maturation are also counted brassinosteroids.

Lately, epi-brassinolide applications on Cabernet Sauvignon, one of the most active brassinosteroids, have accelerated the grape ripening processes, while the brassinazolo, an inhibitor of the biosynthesis of these hormones, showed, on the contrary, an definitely retardant action (Symons et al. 2006). Among the regulators growth, also salicylic acid, applied 2-3 weeks before veraison on Shiraz, was able to delay the development of berries color (Kraeva et al. 1998), as well as some synthetic cytokinin, such as the CPPU (N-2-chloro-4-pyridinyl-N'-phenylurea), applied in preveraison was able to reduce the concentration of soluble solids and berry coloring, and to increase the berries weight and the total acidity (Han and Lee, 2004).

1.1.5 Alternatives cultivation techniques

Early harvest of some production for the establishment of specific oenological products

The most provocative technique is perhaps that proposal from Kontoudakis et al. (2011), in an attempt to produce red wines with lower alcohol content and pH, but still having full phenolic maturity and typicality organoleptic, have successfully tested on Grenache the possibility to make wine with grapes usually eliminated with the thinning of the grapes and get a wine very acid (17.8 g/l), low pH (2.64) and alcohol content (just 5% vol. alcohol), odorless and colorless due to treatments with activated charcoal and bentonite. This wine was then used to blend wines made from grapes of Cabernet Sauvignon, Merlot and Bobal picked at complete phenolic ripening with the practical advantage of reducing the alcohol content of wines and pH without changing the phenolic profile and sensory characteristics. This technique ranging under the name of "double harvest" with which it has been tried to obtain different productions or improve relevant aspects of the wine quality exploiting differentiated harvest and/or combining the results of individual vinification. In this regard, Martinez de Toda and Balda (2011) have obtained less alcoholic and most acids wines combining wine Tempranillo obtained with grapes removed by thinning immediately after veraison with wine produced instead with grapes harvested when the phenolic maturity had reached the highest point. In 2010, on Merlot and Cabernet Sauvignon pruned with a normal production were performed two operations of bunch thinning: 1) classic bunch thinning, performed a little before veraison leaving only one bunch per bud; 2) bunch thinning performed at a titratable acidity of the must equal to 12-13 g/l (approximately towards the end of August), leaving also in this case only one cluster per shoot and using grapes as sparkling with the classic method, fermentation in bottle.

1.2 References

Balda, P., & Martinez De Toda, F. (2011). Delaying berry ripening process through leaf are to fruit ratio decrease. In *Proceedings of "17th International Symposium of the Giesco* (pp. 579-582).

Bernizzoni, F., CIVARDI, S., Van Zeller, M., GATTI, M., & PONI, S. (2011). Shoot thinning effects on seasonal whole-canopy photosynthesis and vine performance in Vitis vinifera L. cv. Barbera. *Australian Journal of Grape and Wine Research*, *17*(3), 351-357.

Böttcher, C., Keyzers, R. A., Boss, P. K., & Davies, C. (2010). Sequestration of auxin by the indole-3-acetic acid-amido synthetase GH3-1 in grape berry (*Vitis vinifera L.*) and the proposed role of auxin conjugation during ripening. *Journal of Experimental Botany, erq074*.

Bureau, S. M., Baumes, R. L., & Razungles, A. J. (2000). Effects of vine or bunch shading on the glycosylated flavor precursors in grapes of Vitis vinifera L. Cv. Syrah. *Journal of agricultural and food chemistry*, *48*(4), 1290-1297.

Carnevali, P., Falcetti, M. (2012). Utilizzo di antitraspiranti a base di pinolene per la modulazione della maturità glucidica. IV Convegno Nazionale di Viticoltura. CONAVI.TO. Asti. 10-11-12 July 2012.

Cartechini, A., & Palliotti, A. (1995). Effect of shading on vine morphology and productivity and leaf gas exchange characteristics in grapevines in the field. *American Journal of Enology and Viticulture*, *46*(2), 227-234.

Cartechini, A., Palliotti, A., & Lungarotti, C. (1998, August). Influence of timing of summer hedging on yield and grape quality in some red and white grapevine cultivars. In *XXV International Horticultural Congress, Part 2: Mineral Nutrition and Grape and Wine Quality 512* (pp. 101-110).

Change, I. P. O. C. (2007). Climate change 2007: The physical science basis.*Agenda*, *6*(07), 333

Davies, C., Boss, P. K., & Robinson, S. P. (1997). Treatment of grape berries, a nonclimacteric fruit with a synthetic auxin, retards ripening and alters the expression of developmentally regulated genes. *Plant physiology*, *115*(3), 1155-1161.

Di Lena, B., Silvestroni, O., Mariani, L., Parisi, S., & Antenucci, F. (2010, August). European climate variability effects on grapevine harvest date time series in the Abruzzi (Italy). In *XXVIII International Horticultural Congress on Science and Horticulture for People (IHC2010): International Symposium on the 931* (pp. 63-69).

Dokoozlian, N. (2009). Integrated canopy management: a twenty year evolution in California. *Recent advances in grapevine canopy management*, 43-52.

DOWNEY, M. O., HARVEY, J. S., & Robinson, S. P. (2004). The effect of bunch shading on berry development and flavonoid accumulation in Shiraz grapes. *Australian Journal of Grape and Wine Research*, *10*(1), 55-73.

Dry, P.R. (1988). Climate change and the Australian grape and wine industry. *The Australian Grapegrower and Winemaker*. 300, 14–15.

Duchêne, E., & Schneider, C. (2005). Grapevine and climatic changes: a glance at the situation in Alsace. *Agronomy for sustainable development*,*25*(1), 93-99.

Filippetti, I., Allegro, G., Movahed, N., Pastore, C., Valentini, G., & Intrieri, C. (2011, August). Effects of late-season source limitation induced by trimming and antitraspirants canopy spray on grape composition during ripening in Vitis vinifera cv Sangiovese. In *Proceedings 17th international symposium GiESCO*(pp. 259-262).

Friend, A. P., & Trought, M. C. (2007). Delayed winter spur-pruning in New Zealand can alter yield components of Merlot grapevines. *Australian Journal of Grape and Wine Research*, *13*(3), 157-164.

Ganichot, B. (2002). Evolution de la date des vendanges dans les Côtes du Rhône méridionales. *Actes des 6e Rencontres rhodaniennes*, 38-41.

Godden, P., & Gishen, M. (2005). The trends in the composition of Australian wine from vintages 1984 to 2004. *Australian and New Zealand Wine Industry Journal*, *20*(5), 21.

Han, D. H., & Lee, C. H. (2004). Effects of GA3, CPPU and ABA applications on the quality of kyoho (Vitis vinifera L. x Labrusca L.) grape. *Acta horticulturae*.

Haselgrove, L., Botting, D., Heeswijck, R. V., Høj, P. B., Dry, P. R., Ford, C., & Land, P. G. I. (2000). Canopy microclimate and berry composition: The effect of bunch exposure on the phenolic composition of Vitis vinifera L cv. Shiraz grape berries. *Australian Journal of Grape and Wine Research*, *6*(2), 141-149.

Jones, G. V., White, M. A., Cooper, O. R., & Storchmann, K. (2005). Climate change and global wine quality. *Climatic change*, *73*(3), 319-343.

Jones, G. V., & Davis, R. E. (2000). Climate influences on grapevine phenology, grape composition, and wine production and quality for Bordeaux, France. *American Journal of Enology and Viticulture*, *51*(3), 249-261.

Kliewer, W. M., & Dokoozlian, N. K. (2005). Leaf area/crop weight ratios of grapevines: influence on fruit composition and wine quality. *American Journal of Enology and Viticulture*, *56*(2), 170-181.

Kontoudakis, N., Esteruelas, M., Fort, F., Canals, J. M., & Zamora, F. (2011). Use of unripe grapes harvested during cluster thinning as a method for reducing alcohol content and pH of wine. *Australian Journal of Grape and Wine Research*, *17*(2), 230-238.

Kraeva, E. L. E. N. A., Andary, C., Carbonneau, A., & Deloire, A. (1998). Salicylic acid treatment of grape berries retards ripening. *VITIS-GEILWEILERHOF-*, *37*, 143-144.

Lazzini, F., Mattii, G., Binda, C. (2012). Effetto di antitraspiranti sulla maturazione di uve Merlot. IV Convegno Nazionale di Viticoltura. CONAVI.TO. Asti. 10-11-12 July 2012.

Marais, J. (2001). Effect of grape temperature and yeast strain on Sauvignon blanc wine aroma composition and quality. *South African Journal for Enology and Viticulture, 22*(1), 47-51.

Marais, J., Calitz, F., & Haasbroek, P. D. (2001). Relationship between microclimatic data, aroma component concentrations and wine quality parameters in the prediction of Sauvignon blanc wine quality. *S Afr J Enol Vitic, 22*(1), 22-26.

Martinez De Toda F., Balda P., (2011). Decreasing the alcohol level in quality red wines by the double harvest techniques. Proc. 17th Int. Symp. Giesco, Aug. 29th - 2nd Sept., Asti - Alba: 463-466.

McIntyre, G. N., Lider, L. A., & Ferrari, N. L. (1982). The chronological classification of grapevine phenology. *American Journal of Enology and Viticulture, 33*(2), 80-85.

Palliotti, A. (1992). Energia radiante, produttività delle foglie e fotosintesi in Vitis vinifera L. Tesi di Dottorato di Ricerca, Istituto di Coltivazioni Arboree, Università di Perugia.

Palliotti, A., & Cartechini, A. (1998, August). Cluster thinning effects on yield and grape composition in different grapevine cultivars. In *XXV International Horticultural Congress, Part 2: Mineral Nutrition and Grape and Wine Quality 512* (pp. 111-120).

Palliotti, A., Silvestroni, O. (2004). Ecofisiologia applicata alla vite. In “Viticoltura ed Enologia Biologica: Mercato, Tecniche di Gestione, Difesa, Vinificazione e Costi”. Edagricole: 41-92.

Palliotti, A., Poni, S., Petoumenou, D., Vignaroli, S. (2008B). Limitazione modulata della capacità fotoassimilativa delle foglie mediante antitraspiranti ed effetti su quantità e composizione dell’uva. Atti “II Conv. Naz. Viticoltura”, Marsala 14- 19 luglio. Italus Hortus 17 (suppl.3): 21-26.

Palliotti, A., Di Ciano, N., Taticchi, A. (2008c). Montepulciano e tendone binomio da migliorare. L’Inf. Agr. 36: 45-50.

Palliotti, A., PONI, S., Berrios, J. G., & BERNIZZONI, F. (2010). Vine performance and grape composition as affected by early-season source limitation induced with anti-transpirants in two red Vitis vinifera L. cultivars.*Australian Journal of Grape and Wine Research*, *16*(3), 426-433.

Palliotti, A., Silvestrioni, O., Poni, S., (2011b). Controllo degli zuccheri nell’uva con il Pinolene. L’Inf. Agr., supp 13: 29-32.

Palliotti, A., Panara, F., Silvestroni, O., Lanari, V., Sabbatini, P., Howell, G. S., ... & Poni, S. T. E. F. A. N. O. (2013). Influence of mechanical postveraison leaf removal apical to the cluster zone on delay of fruit ripening in Sangiovese (Vitis vinifera L.) grapevines. *Australian Journal of Grape and Wine Research*,*19*(3), 369-377.

Palliotti, A., Silvestroni, O., Leoni, F., & PONI, S. (2012). Maturazione dell’uva e gestione della chioma in Vitis vinifera: processi e tecniche da riconsiderare in funzione del cambiamento del clima e delle nuove esigenze di mercato. *Italus Hortus*, (19), 1-15.

Pearce, I.; And Coombe, B.G. (2004). Grapevine Phenology. In: P. Dry and B.G. Coombe (Eds). Viticulture Volume 1 – Resources. (Winetitles: Adelaide. South Australia) pp. 150–166.

Poni, S., Palliotti, A., Mattii, G., Di Lorenzo, R. (2007). Funzionalità fogliare ed efficienza della chioma in Vitis vinifera L. Italus Hortus 14 (4): 28-45.

Scafidi, P., Pisciotta, A., Patti, D., Tamborra, P., Di Lorenzo, R., & Barbagallo, M. G. (2013). Effect of artificial shading on the tannin accumulation and aromatic composition of the Grillo cultivar (Vitis vinifera L.). *BMC plant biology*,*13*(1), 175.

SCHULTZ, H. (2000). Climate change and viticulture: A European perspective on climatology, carbon dioxide and UV-B effects. *Australian Journal of grape and wine research*, *6*(1), 2-12.

Smart, R. E., Alcorso, C., & Hornsby, D. A. (1980). A comparison of winegrape performance at the present limits of Australian viticultural climates-Alice Springs and Hobart [Northern Territory, Tasmania]. *Australian Grapegrower and Winemaker*.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., ... & Miller, H. L. (2007). IPCC, 2007: Climate change 2007: The physical science basis. *Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change*.

Spayd, S. E., Tarara, J. M., Mee, D. L., & Ferguson, J. C. (2002). Separation of sunlight and temperature effects on the composition of Vitis vinifera cv. Merlot berries. *American Journal of Enology and Viticulture*, *53*(3), 171-182.

Symons, G. M., Davies, C., Shavrukov, Y., Dry, I. B., Reid, J. B., & Thomas, M. R. (2006). Grapes on steroids. Brassinosteroids are involved in grape berry ripening. *Plant Physiology*, *140*(1), 150-158.

Stoll, M., Lafontaine, M., & Schultz, H. R. (2010). Possibilities to reduce the velocity of berry maturation through various leaf area to fruit ratio modifications in Vitis vinifera L. Riesling. *Le Progrès agricole et viticole*, *127*(3), 68-71.

Tittmann, S., Stöber, V., Bischoff-Schaefer, M., & Stoll, M. (2013). Application of anti-transpirant under greenhouse conditions of grapevines (*Vitis vinifera* cv. Riesling and cv. Müller-thurgau) reduce photosynthesis. 07/2013; DOI:ISSN 0254-0223 In the proceedings of the 18th International GiESCO. Porto. 7-11 July 2013. 8-12. Volume: 28

Vierra, G. (2004). Pretenders at the Table–Are table wines no longer food friendly. *Wine Business Monthly*, *11*(7).

Webb, L. (2006). *The impact of greenhouse gas-induced climate change on the Australian wine industry* (Doctoral dissertation, PhD Thesis. School of Agriculture and Food Systems, University of Melbourne, Parkville Victoria, 277pp).

2 AIMS OF THE STUDY

Today two new factors, known as global warming, or the progressive heating the surface of the planet and "drink light and/or knowingly ", ie the growing demand by the markets, both domestic and foreign, of wines with moderate alcohol content, require to reconsider the current production models. At the base of this need, there are some phenomena emerging such as: 1) advance of all phenological phases; 2) acceleration of the maturation process of the grapes with significant increases in the concentration of sugar musts and therefore an increase of alcohol content of wine; 3) accelerated depletion of the framework of the acidic musts and rapid increases of pH values resulting in possible instability of microbiological masses in pre-fermentation; 4) Decoupling between the technological maturity of the grape, always more accelerated, and the phenolic maturity, more delayed within a framework particularly unsuitable for red grapes; 5) increasing phenomenon fast and irreversible dehydration phenomena of the grape berries until the occurrence of serious damage by sunburn. In this context it is necessary to focus attention on future scenarios and define interventions both programmatic, ie to plan the new arrangements of viticulture Millennium, both setup point of cultivation methods likely to overcome or at least dab, at least in the short and medium term, the negative effects arising from these new issues. Aim of this study is to evaluate the use of a natural anti-traspirant for modular glucose maturity, reducing the sugars accumulation in the grapes and the alcohol content of the wines produced. The application of the product were carried out on different cultivars and in different climatic environments: Southern Italy and Southern Australia. The study compared two cultivars widely grown in Campania: Aglianico and Falanghina and two cultivars widely grown in South Australia Shiraz and Semillon. The climatic environment were quite different, the first caracterized by a Mediterranean climate, for the trial conducted in Italy, and the second caracterized by a very warm and dry climate for the trial conducted in Australia. The trials compared also the effects of bunch thinning as tools to control the accumulation of sugars in different cultivar and in two different cultivation enviroment.

3 TRIAL 1 (SOUTHERN ITALY)

Anti-transpirant effects on grape physiology and berry and wine composition of Aglianico and Falanghina (*Vitis vinifera* L.) grown in South Italy

Summary

Plant growth, yield and quality are highly dependent on climate. In the last few decades the trend of increasing global temperatures has affected the accumulation of sugars in berries and hence the degree of alcohol in resultant wines. Therefore numerous studies have considered different agronomic practices that limit photosynthetic activity. The aim of our study was to evaluate the effect of a natural anti-transpirant on grapevine physiology and berry and wine composition on two cultivars. In 2013 and 2014, in South Italy, Aglianico and Falanghina vines were treated at veraison with the anti-transpirant Vapor Gard® (T) and compared with a control (C) sprayed just with water. A bunch thinning (BT) treatment was also applied to both the Vapor Gard® treatment and the control. For each treatment was assessed vegetative response (pruning weight) and production (production and number of bunches per plant, TSS, pH, TA, polyphenols, anthocyanins) of individual varieties. Consideration was also the effectiveness of the film terpene that has come to form on the leaves, limiting gas exchange, through measurements of net photosynthesis and transpiration (LI-6400). The results demonstrate that the application of anti-transpirant has reduced assimilation rate (A), transpiration rate (E), stomatal conductance (gs), sugars berries accumulation (TSS) and wine alcohol degrees (% vol.). No significant differences between treatments were observed for other berry and wine compositional measures taken between cultivars. This method may be a useful tool to reduce berry sugar content which can result in lower alcohol content in wines.

3.1 Materials and Methods 1

3.1.1 Experimental site, design and treatments

The trial was carried out in the Cooperativa Agricola La Guardiense, in Benevento province (Guardia Sanframondi, Benevento, Campania Region, lat. 41°1532 N, long. 14°3554 E). The farm lies at an altitude of 300 m above sea level (a.s.l.). The experimental trial was conducted on a franco-loamy soil type in both vineyards. The study was carried out over the 2013 and 2014 growing seasons on two winegrape (*Vitis vinifera* L.) cultivars: Aglianico grafted onto 110 Richter and Falanghina grafted onto 1103 Paulser. Aglianico vines were planted with 2.40 m spacing between rows and 1.40 m on the row. Falanghina vines were planted at 2.50 × 1.40 m inter and intrarow. The vines were trained to a bilateral guyot and hand-pruned to 30 nodes per vine, 15 for each long cane. All treatments for both cultivars were not irrigated during the growing season. Pest management was carried out according to local standard practice. Daily min, max and average air temperature (°C) and montly rainfalls (mm) data recorded in both years and it was taken from a weather station close to the vineyard site and precisely in Guardia Sanframondi (Bn). A randomised block design including four replicated blocks of each treatment was used for both culivars. In total, 20 vines per treatment were selected for Aglianico and 20 for Falanghina. Adjacent rows were selected: each row had 4 block with 5 vines for different treatment. Half of the vines of each block were assigned to antitranspirant Vapor Gard treatment (VG) and the vines of the other half were used as an unsprayed control (C). Three days before the VG application, to each treatments a decrease in bunches number, bunch thinning (BT), treatment was applied at E-L stage X (Baggiolini, 1952), with BT in Aglianico amounting to 50% of all bunches, and 30% of all bunches in Falanghina.

Four treatments for each cultivar, finally, were compared: a spray application of the anti-transpirant Vapor Gard® (VG) (T = treated vines), a water spray application (C = control vines), a spray application of the anti-transpirant Vapor Gard® with bunch thinning (BT) and a water spray application with bunch thinning. The anti-traspirant product used was Vapor Gard (Intrachem Bio Italia, Grassobbio, Italy) a water emulsifiable organic concentrate for use on plants designed to reduce transpiration by forming a clear, soft and flexible film that retards normal traspiration loss. Its active ingredient is di-1-p-menthene ($C_{20}H_{34}$), a terpenic polymer also known as pinolene. VG was prepared as a 2% solution in water and stirred slowly to form an emulsion before treatment, and all the leaves of the canopy located above the cluster area were sprayed using a portable pump. The abaxial surfaces of the leaves were wet well in order to cover the stomatal pores (Palliotti et al. 2013). The entire canopy of all T vines was sprayed with VG until run-off.

The VG treatments were applied one month about before harvest for both cultivars. This date corresponded to full veraison (E-L stage 35) for cultivars, as described according to Baggiolini, 1952. Aglianico and Falanghina was harvested one month after spraying. In 2013 growing season VG was applied on 02 August for Falanghina and on 02 September for Aglianico. In 2014 growing season VG was applied on 31 July for Falanghina and 01 September for Aglianico. Aglianico and Falanghina (AOC) were harvested one month after spraying, exactly in the year 2013 on 15th October for Aglianico and on 08th October for Falanghina, while in the year 2014 on 09 October for Aglianico and on 30 September for Falanghina.

3.1.2 Physiological measurements

Three Days after anti traspirant sprayed in growing season in the Aglianico and Falanghina vineyards, single leaf gas exchange readings of both T and C vines bunch thinning and not were taken at midday of clear days using a portable *LI-6400*, Portable Photosynthesis System *(LICOR, Lincoln, Nebraska USA).*

Assimilation rate (A), transpiration rate (E) and stomatal conductance (gs) were calculated from inlet and outlet CO_2 and H_2O relative concentrations. Data were obtained using a *LI-6400*, Portable Photosynthesis System *(LICOR, Lincoln, Nebraska USA)*. Intrinsic water use efficiency (WUEi) was then derived as the A to gs ratio as described by Paliotti *et al.* (2010). Measurements were taken on ten mature and fully expanded leaves in each treatment. The instrument provides the Fv'/Fm' ratio, which is a widely accepted indicator of the maximum photochemical efficiency of photosystem II (PSII) in light adapted leaves.

On the same days of gas exchanges measurements and chlorophyll *a* fluorescence, temperature of leaves was measured in all treatments using the thermal infrared camera Flir SC-640 (FLIR Systems, Inc. 27700 SW Parkway Avenue Wilsonville, OR 97070). The instrument operates in the wavebands 8–12 lm, has a thermal resolution of 0.1 8C, and produces pictures with spatial resolution of 120 x 120 pixels. The areas of interest for analysis in the imager's software were outlined, manually, by comparing thermal and normal digital images. All thermal images were taken with the thermal imager on a tripod perpendicular to the area being imaged. Images at canopies scale were taken: 1.5 and 0.9 m from the canopies and leaves, respectively, capturing areas of: 50 cm^3 50 cm and 29 cm^3 29 cm, respectively.

Stomatal conductance (gs) was measured at midday on ten mature and fully expanded leaves per treatment and per variety using a non-steady state porometer (AP4. Delta-T Devices. Cambridge. UK). One time for week after VG application, at varying intervals until harvest.

3.1.3 Growth, yield and grape composition

Each year before harvest and during the growing season, beginning from veraison, fifty berries for three different replicates for each treatments were randomly collected about each week, sampling point to obtain grape maturity data, to determine the harvest date for each variety and to appreciate the differences between the thesis compares. The berries were collected from random bunches and from different sections of the bunc top, middle and bottom and from exposed and non-sun exposed bunch sides to avoid bias. The berries were also weighed to monitor average weight with a digital scales precision weighing (Acculab sartorius Group ECON EC-411).

The fifty berries for three different replicates and for each treatment were manually crushed, juice was used to make a juice sample for measurement trend of the grape ripening: soluble solids (°Brix), pH and titratable acidity (TA). Total soluble solids (TSS) concentration was determined with a digital refractometer (Model L-R 01 Digital Refractometer, Maselli Misure S.p.a., 43100 Parma -Italy). pH was measured by a digital pHmeter (Crison Instrument GLP 21 pH) and titratable acidity (TA) using official method for titrable acidity determination, with 0.1 N NaOH to a pH 8.2 end point and was expressed as g/L of tartaric acid. A day before the Aglianico harvest, in both years growing season, 10 bunches for each Aglianico treatment, were taken and estimating phenolic maturity in grapes, according to Glorie's method (Glories, 1978).

The experimental vines were individually and manually picked, in the year 2013 on 15th October for Aglianico and on 08th October for Falanghina, while in the year 2014 on 09 October for Aglianico and on 30 September for Falanghina. Yield and bunch number per vine per each treatment were determined at harvest time. At each harvest date 150 kg of fruit per replicate were randomly harvested and transported to the laboratory. The bunches were collected from both sides of the vines and from shaded and non-shaded vine sections to avoid bias. Anthocyanin and phenolic contents (expressed as mg/Kg) were determined on berry. The total anthocyanin and phenolic contents were determined by Foss WineScan TM SO_2.

During the winter and after each growing season was taken 1-year-old pruning weight and it was recorded in the Aglianico and Falanghina vineyard on each vine and used to calculate the pruning weight.

3.1.4 Microvinification and wine analysis

In 2013 and 2014, wines were made using microvinification techniques. At harvest, grapes from VG-treated, C vines, vines with and without bunch thinning were harvested manually and transported to the experimental winery in 20 kg plastic boxes. Each treatment was mechanically crushed, destemmed, transferred to fermentation containers, sulfited with 35 mg/L SO_2, and inoculated with 20 mg/hL of a commercial yeast strain (BCS 103 Springer oenologie). Wines were fermented for 16 to 18 days on the skin and punched down twice daily (just for red wine), with the fermentation temperature ranging from 20 to 23°C. After alcoholic fermentation, the wines were pressed at 0 Brix and inoculated with 30 mg/L Oenococcus oeni (Lalvin Elios 1 MBR; Lallemand). After completion of malolactic fermentation, the samples were racked and transferred to glass bottle and 25 mg/L SO_2 was added. Two months later, the wines were racked again, bottled into 750 mL bottles, and then closed with cork stoppers. The wines were analyzed for alcohol, titratable acidity, and pH. Total phenol and anthocyanin concentrations were determined with a Foss WineScan TM SO_2. All determinations were carried out in duplicate, yielding four replicates per treatment. On wine products was carried out the 'sensory analysis’ using the official method of the International Union of Oenologue, to describe the wine aroma profile. A panel of 12 judges composed of Agri-Food experts (7 males and 5 females between the ages of 22 and 55 years) participated in this research. All of the judges were experienced wine tasters and six of them had previously participated in a similar study that characterized sensory analysis of wines.

3.1.5 Statistical analysis

Multivariate analysis of variance (ANOVA), mean separation by Duncan’s multiple range test ($p < 0.05$) were performed using the statistical package XL-Stat Version, 2013.

3.2 Results and discussion 1

From the trend of average monthly temperatures recorded at the farm in Guardia Sanframondi and the monthly rainfalls for the same area in 2013 and 2014 (Fig. 7A), it was observed that minimum temperatures were 6.1, 5.1, 5.9 °C respectively during January, February and December in the year 2013. Peak maximum temperatures were recorded during August (22.4 °C). Same trend showed the temperatures measured in the second year of study: but the minimum temperatures in this year were higher, 7.75 and 9.29 °C in January and February respectively, except for December (-1.5 °C), while maximum temperatures seemed to remain quite similar to prior year (21.34 °C, once again during August) (Fig. 7B). In 2013 and 2014 years at Guardia Sanframondi there was a total rainfall of 2,037.2 mm and 1,734.8 respectively.

The rainiest months are March and November for the year 2013 (422.8 and 303 mm respectively) and January and February with 278 and 223.6 mm respectively for the year 2014.

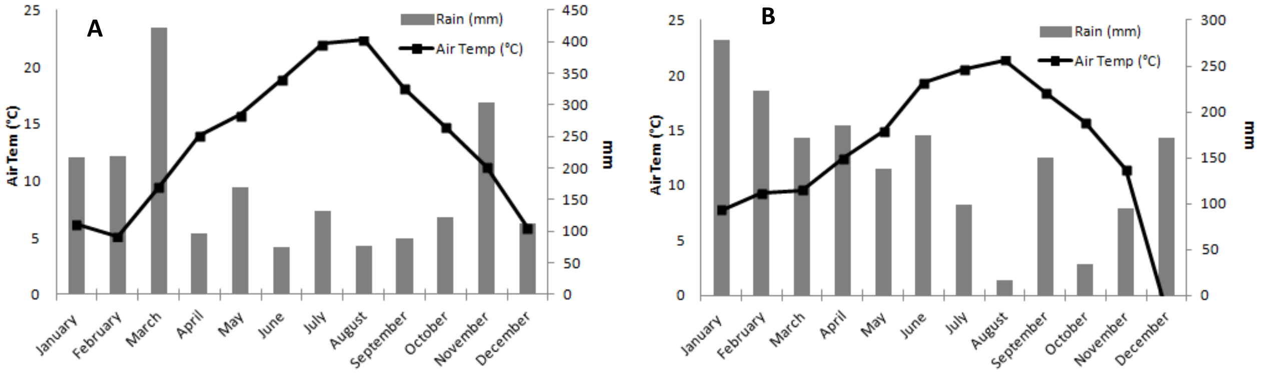

Figure 7 - Monthly mean air temperature (°C) and monthly rainfalls (mm) recorded in both years 2013 (A) and 2014 (B). The line indicate average monthly temperature (°C) and the bars the monthly rain (mm).

In both years 2013 and 2014, from VG application to harvest time we monitored stomatal conductance (gs) for both Aglianico and Falanghina cvs. As reported in Figure 8, it is possible to see how these parameters evolve during the season from VG application to harvest time and to appreciate the significant differences in stomatal conductance (gs) between treatments. Stomatal conductance of Vapor Gard treatment is lower for VG treated vines in the first 20 days after application (Fig. 8).

Stomatal conductance (gs) was significantly reduced each year in the sprayed Aglianico vines as compared with C vines (Figure 8). In 2013 year Aglianico showed a less leaf conductance amounted to 0.47 *vs* 0.72 (mol m^{-2} s^{-1}) for treated and control vines respectively and 0.21 *vs* 0.73 (mol m^{-2} s^{-1}) for treated and control vines respectively bunch thinning after three days of application (Fig. 8A). Same trend we can observed for Aglianico vines treated and in the year 2014 (Fig. 8B). It's interesting also described same trend between treated vine and bunch thinning treated vine, bunch thinning treated vine results in both years less leaf conductance. Falanghina treated vines shows same state of Aglianico (Fig. 9). In the year 2013 less leaf conductance amounted to 0.46 *vs* 0.75 (mol m^{-2} s^{-1}) for treated and control vines respectively and 0.24 *vs* 0.61 (mol m^{-2} s^{-1}) for treated and control vines respectively bunch thinning after three days of application (Fig. 9A). Same trend we can observed for Falanghina vines treated and in the year 2014 (Fig. 9B).

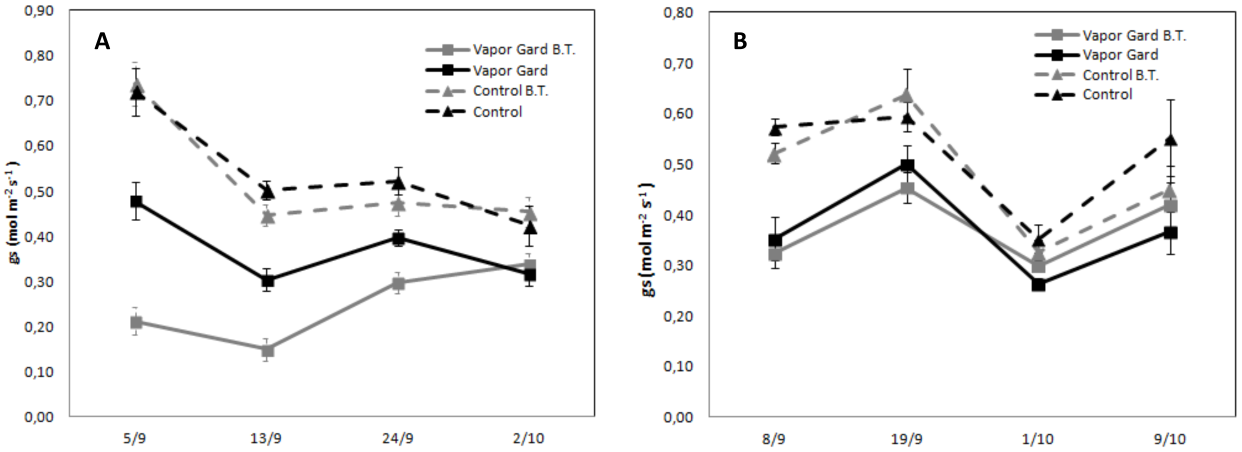

Figure 8 - Stomatal conductance (gs) measured with porometer in Aglianico vines in 2013 (A) and 2014 (B). Data are mean ± SE.

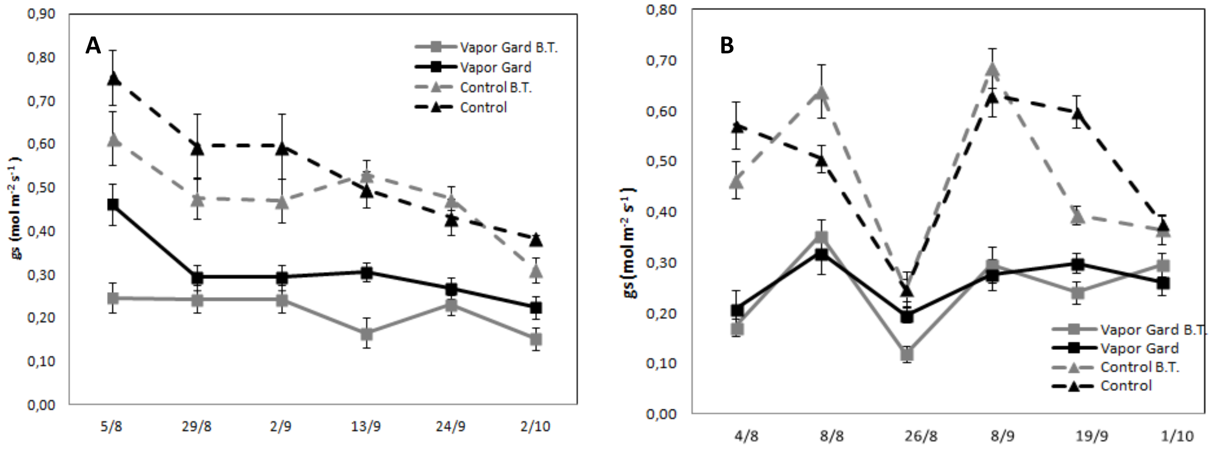

Figure 9 - Stomatal conductance (gs) measured with porometer in Falanghina vines in 2013 (A) and 2014 (B). Data are mean ± SE.

Few days after VG treatment, the sprayed leaves showed a great reduction in leaf assimilation (A), traspiration rate (E) and stomatal conductance (gs), in both years 2013 and 2014 and in both cultivars Aglianico e Falanghina (Figures 10-11-12-13-14-15). Leaf assimilation (A) Aglianico cultivar recorded data for 2013 years were: 17.4 *vs* 26.6 (µmol $m^{-2}s^{-1}$) for Vapor Gard and Control respectively (Fig. 10A). Palliotti et al. (2013) reported similar observations. More reduction in leaf assimilation we can see for bunch thinning treatment: 25.4 *vs* 10.8 (µmol $m^{-2}s^{-1}$) for Vapor Gard B.T. and Control B.T. respectively in the year 2013 (Fig. 10A). Same data we observed in the year 2014. Aglianico VG treatment showed a reduction in leaf assimilation as 34.7 % and 57.6 % for Aglianico VG without and with bunch thinnig treatment respectively in the year 2013 and 62.4 % and 45.3 % in the year 2014 (Fig. 10B).

Same data we can report in Falanghina cultivar: in the year 2013 leaf assimilation was 11.6 *vs* 16.3 (µmol $m^{-2}s^{-1}$) for Vapor Gard and Control respectively. The same result observed in treatment with bunch thinning: 11.5 vs 15.4 (µmol $m^{-2}s^{-1}$). It caused so a reduction as 25.2% for bunch thinning treatment and 29% for Vapor Gard and Control treatment in Falanghina cultivar in 2013 year (Fig. 11A). The Vapor Gard application repeted in the second year 2014 have do same results of last year 2013 (Fig. 11B): Vapor Gard treatment show an assimilation rate as 4.96 *vs* 10.27 (µmol $m^{-2}s^{-1}$) same result for bunch thinning treatment: 6.34 *vs* 12.04 (µmol $m^{-2}s^{-1}$) (Fig. 11B). After VG application, sprayed leaves had lower A than control leaves according with results shows by Palliotti el al. 2013. No statistical difference was found in bunch thinning and no bunch thinning treatments, whereas in the VG-treated vines, assimilation rate reduced as compared to C vines.

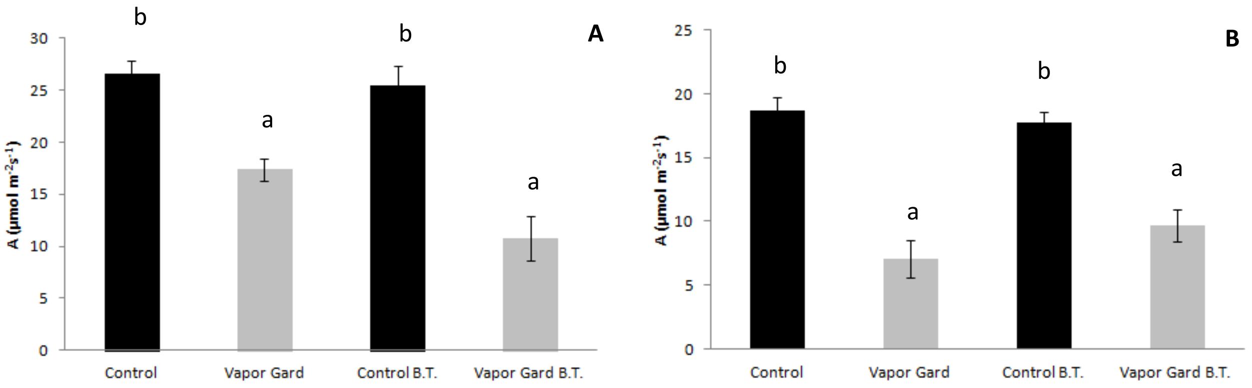

Figure 10 - Assimilation rate (*A*) measured in the years 2013 (A) and 2014 (B) on fully expanded Aglianico leaves sprayed with antitranspirant Vapor Gard® (VG) at 2% or left unsprayed (Control) with or without bunch thinning (BT). Data are mean ± SE. Same letter indicates not significant differences at Duncan post hoc test (p<0.05).

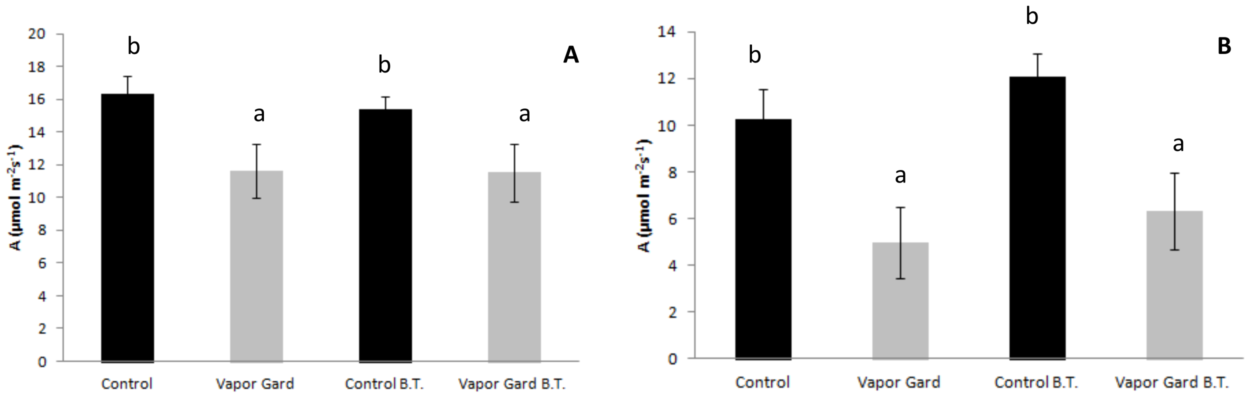

Figure 11 - Assimilation rate (*A*) measured in the years 2013 (A) and 2014 (B) on fully expanded Falanghina leaves sprayed with antitranspirant Vapor Gard® (VG) at 2% or left unsprayed (Control) with or without bunch thinning (BT). Data are mean ± SE. Same letter indicates not significant differences at Duncan post hoc test (p<0.05).

Traspiration rate (E) showed in the year 2013 and 2014 significaly differences between treated vine (T) and Control (C) for both cultivar. VG sprayed on Aglianico at veraison caused a 66.6 % reduction of leaf transpiration rate (E) after application in the 2013 year and 42.2 % in 2014 year compared to the control vines. These effects were the same when bunch thinning was also applied (Fig. 12A). In the year 2013 E measured three days after VG application was 5.70 mmol H_2O m^{-2}s^{-1} in the control and 2.91 mmol H_2O m^{-2}s^{-1} in the VG treated Aglianico vines. The bunch thinning treatment also showed major differences in E: the control with BT was 5.92 mmol H_2O m^{-2}s^{-1} and the sprayed treatment 0.92 mmol H_2O $m^{-2}s^{-1}$ in Aglianico vines (Fig. 12A). Same results with statistically significant differences between treated and control vines were recorded in the year 2014 for Aglianico (Fig. 12B). In line with the trend of Aglianico is also Falanghina cv: in the year 2013 E measured three days after VG application was 6.81 mmol H_2O $m^{-2}s^{-1}$ in the control and 4.23 mmol H_2O $m^{-2}s^{-1}$ in the VG treated Falanghina vines (Fig. 13A). The bunch thinning treatment also showed major differences in E: the control with BT was 5.29 mmol H_2O $m^{-2}s^{-1}$ and the sprayed treatment 3.58 mmol H_2O $m^{-2}s^{-1}$ in Falanghina vines. Same results with statistically significant differences between trated and control vines were recorded in the year 2014 for Falanghina (Fig. 13B). Independently of the bunch thinning the vines treated show a lower transpiration rate (E) respect control vines (Fig. 12-13).

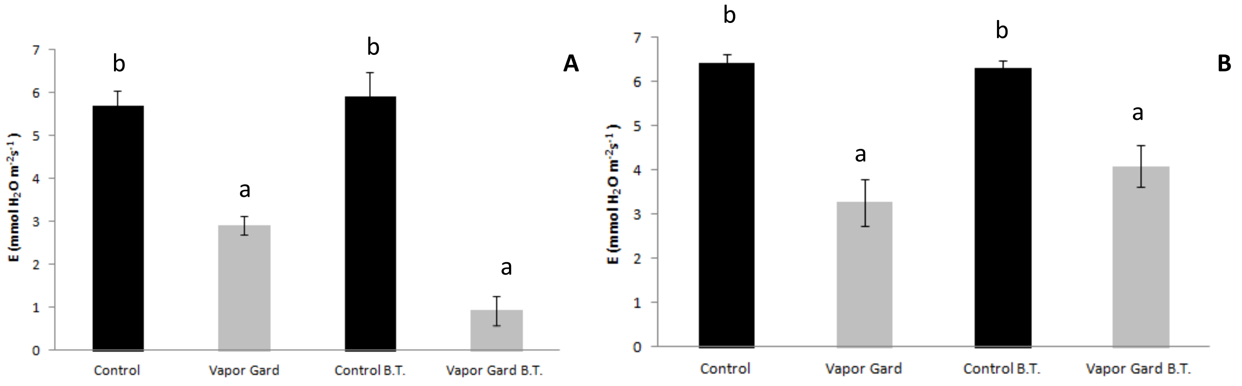

Figure 12 - Transpiration rate (E) measured in the years 2013 (A) and 2014 (B) on fully expanded Aglianico leaves sprayed with antitranspirant Vapor Gard® (VG) at 2% or left unsprayed (Control) with or without bunch thinning (BT). Data are mean ± SE. Same letter indicates not significant differences at Duncan post hoc test (p<0.05).

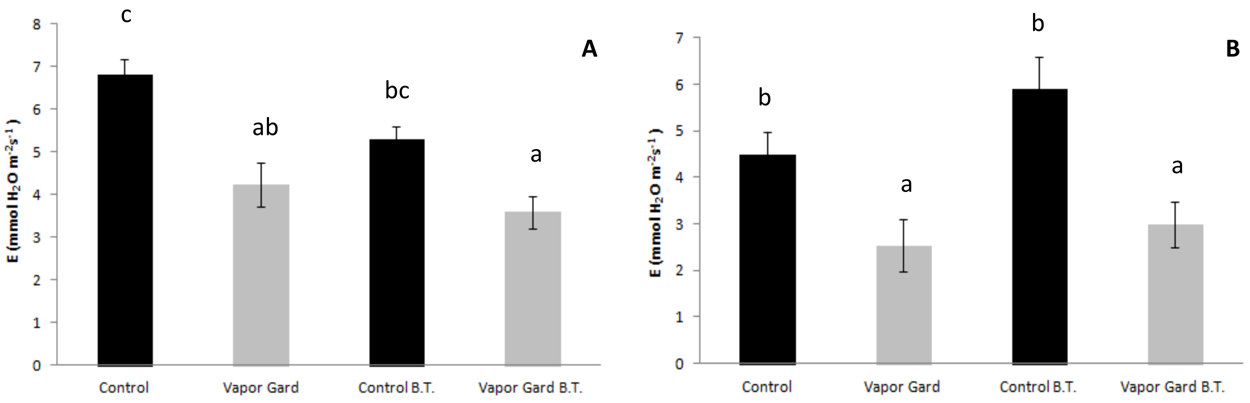

Figure 13 - Transpiration rate (E) measured in the years 2013 (A) and 2014 (B) on fully expanded Falanghina leaves sprayed with antitranspirant Vapor Gard® (VG) at 2% or left unsprayed (Control) with or without bunch thinning (BT). Data are mean ± SE. Same letter indicates not significant differences at Duncan post hoc test (p<0.05).

In terms of stomatal conductance (g_s), measured with Licor instrument a few days after application with Vapor Gard, the minimum was recorded in the VG treatment with bunch thinning vines, 0.03 mol m^2s^{-1} for Aglianico (Fig. 14A) and 0.09 mol m^2s^{-1} for Vapor Gard treated vines. Same trend it's shown in the year 2014, in fact same results with statistically significant differences between treated and controlled vines were recorded in the second year of study for Aglianico. Same values it can be observed in Control vines in both years for Aglianico: bunch thinning treatment didn't show any differences, the tipical average value of Control vines is around 0.18 mol m^2s^{-1} in 2013 and 0.25 mol m^2s^{-1} in 2014 year (Fig. 14). Stomatal conductance (g_s) for Falanghina three days after Vapor Gard spraying treatment were higher in Control leaves, showing values around 0.13 mol m^2s^{-1}, any diffences statistically significant showed treatment with bunch thinning and treatment without bunch thinning (Fig. 15A). Vapor Gard leaves showed instead lower value around 0.09 mol m^2s^{-1} in 2013 and 0.05 mol m^2s^{-1} in 2014 (Fig. 15AB). Same results showed other studies by others authors (Palliotti et al. 2010 and Tittmann et al. 2013): VG treated plants showed a reduced photosynthesis rate, and stomatal conductance (under field and greenhouse conditions) compared to control plants.

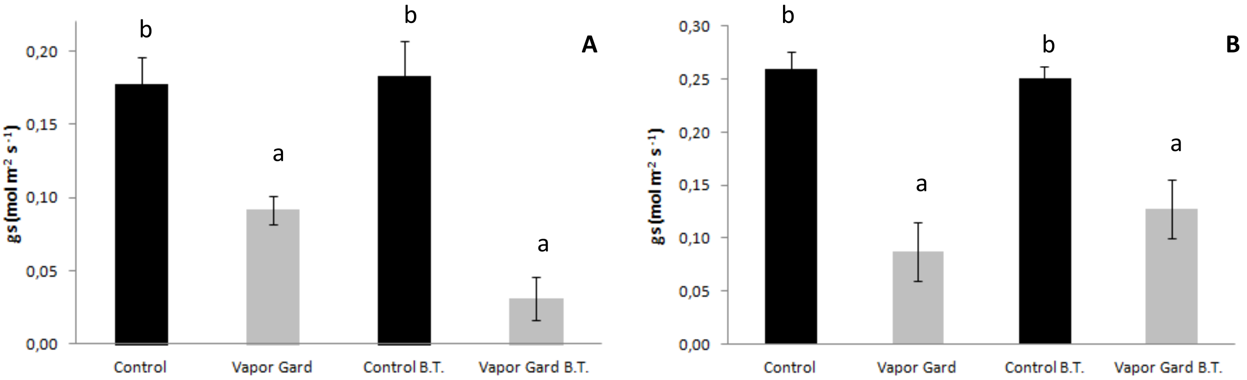

Figure 14 - Stomatal conductance (gs) measured in the years 2013 (A) and 2014 (B) on fully expanded Aglianico leaves sprayed with antitranspirant Vapor Gard® (VG) at 2% or left unsprayed (Control) with or without bunch thinning (BT). Data are mean ± SE. Same letter indicates not significant differences at Duncan post hoc test ($p<0.05$).

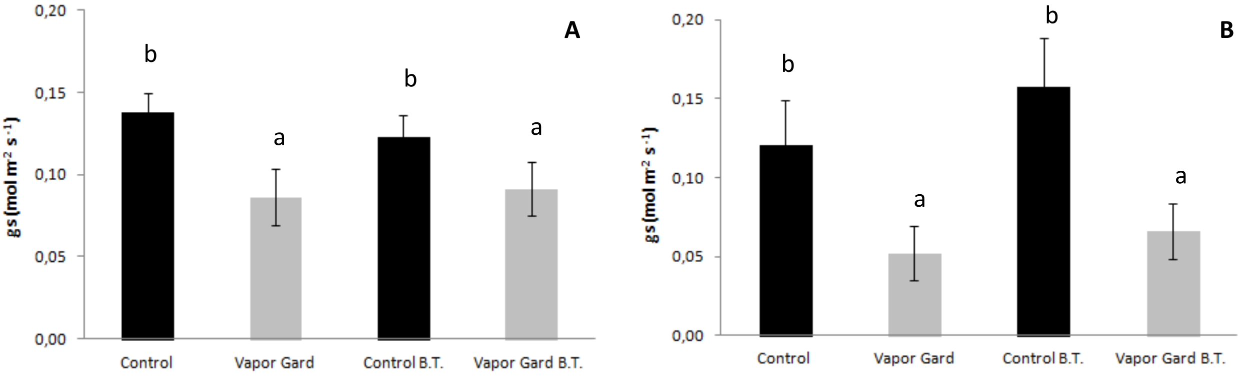

Figure 15 - Stomatal conductance (gs) measured in the years 2013 (A) and 2014 (B) on fully expanded Falanghina leaves sprayed with antitranspirant Vapor Gard® (VG) at 2% or left unsprayed (Control) with or without bunch thinning (BT). Data are mean ± SE. Same letter indicates not significant differences at Duncan post hoc test ($p<0.05$).

These finding are comparable with others studies of other authors: Palliotti et al. (2013) described as the reduction of stomatal conductance (gs), A, and E rates following VG spraying was accompanied by a marked reduction (from 60 to 70% compared to leaves of control vines) of substomatal CO_2 concentration (182 to 218 ppm in control leaves versus 112 to 165 ppm in VG-treated leaves), it is apparent that this behavior was linked to some physical impairment of stomatal opening and function.

Reverse trend can instead shows for intrinsic water use efficiency (WUEi) derived as the A to gs ratio. In the year 2013 WUEi measured three days after VG application was 153.46 µmol mol^{-1} in the Control and 193.97 µmol mol^{-1} in the VG treated Aglianico vines (Fig. 16A). The bunch thinning treatment also showed same trend in WUEi: the control with BT was 142.51 µmol mol^{-1} and the sprayed treatment 227.57 µmol mol^{-1} in Aglianico vines. Same results with statistically significant differences between treated and control vines were recorded in the year 2014 for Aglianico: 72.51 *vs* 87.92 (µmol mol^{-1}) for Vapor Gard vines without bunch thinning and 71.23 *vs* 81.91 (µmol mol^{-1}) for VG treated vines with bunch thinning (Fig. 16B). The same trend shows WUEi of Falanghina, but with differences less marked: in the 2013 year we can observe values as 119.22 *vs* 142.79 (µmol mol^{-1}) for VG treated vines and Control vines respectively without bunch thinning. Same trend for bunch thinning VG treated vines has been investingated: 127.29 *vs* 130.22 (µmol mol^{-1}) for VG leaves and Control leaves respectively (Fig. 10A). Same results for Falaghina VG treated vines in the 2014 year has been showed (Fig. 16B).

After VG application, A and E rates again decreased, demonstrating the effectiveness of VG in rapidly reducing stomatal opening upon treatment. Thereafter, the capacity for carbon gain of VG-treated leaves remained limited for a period of four weeks until harvest, when gs again converged toward levels seen in C leaves (Fig. 14-15). Conversely, at harvest, sprayed leaves still had lower E than control leaves. The depression of E after VG application resulted in a significant increase of WUEi in VG relative to C vines and was of similar duration, suggesting a lower water loss in VG relative to C vines, while both achieved a similar carbon again according to that reported in the literature (Palliotti et al. 2010 and Tittmann et al. 2013).

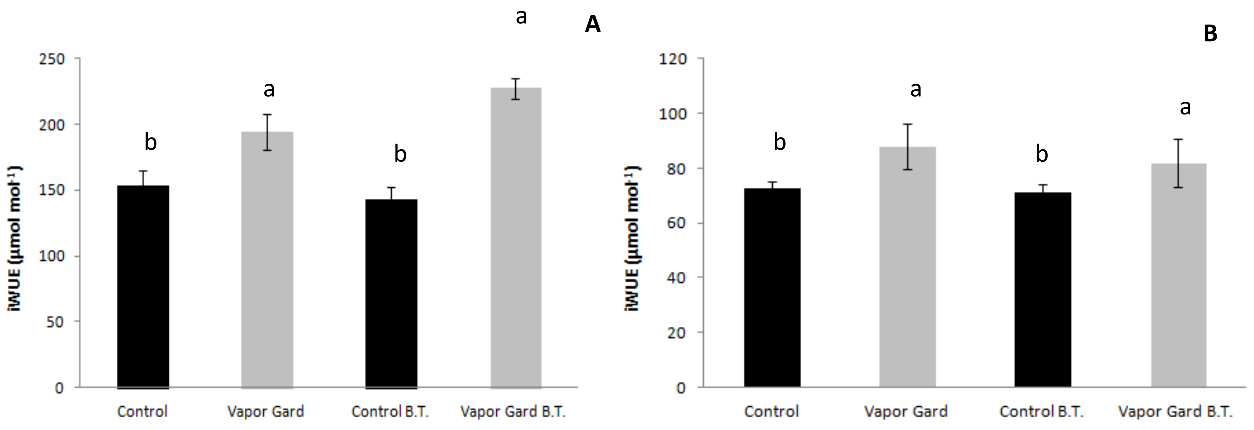

Figure 16 - Intrinsic water use efficiency (WUEi) calculated as A/gs measured in the years 2013 (A) and 2014 (B) on fully expanded Aglianico leaves sprayed with antitranspirant Vapor Gard® (VG) at 2% or left unsprayed (Control) with or without bunch thinning (BT). Data are mean ± SE. Same letter indicates not significant differences at Duncan post hoc test (p<0.05).

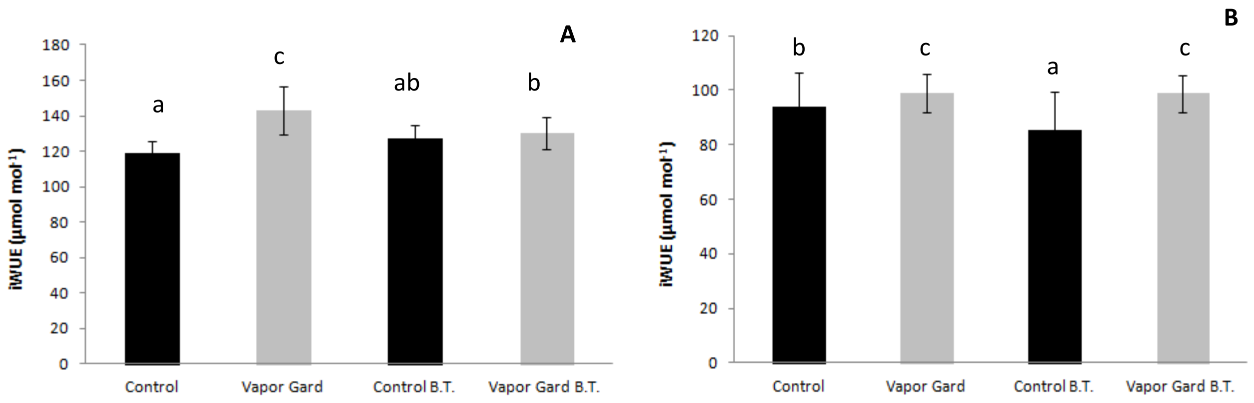

Figure 17 - Intrinsic water use efficiency (WUEi) calculated as A/gs measured in the years 2013 (A) and 2014 (B) on fully expanded Falanghina leaves sprayed with antitranspirant Vapor Gard® (VG) at 2% or left unsprayed (Control) with or without bunch thinning (BT). Data are mean ± SE. Same letter indicates not significant differences at Duncan post hoc test (p<0.05).

These findings are comparable with those reported in the literature (Palliotti et al. 2010 and Tittmann et al. 2013). As reported by Palliotti et al. (2010), the decrease in transpiration rate can be attributed to an increase in resistance to the water transport related to the film-forming antitranspirant. For both varieties a stronger effect on E than on A was found. In agreement with the findings of Palliotti et al. (2010 and 2013) and Tittmann et al. (2013) in their greenhouse experiments, our study showed that, two weeks after application, Aglianico plants were able to recover, although a reduced A compared to the control was still observed. As shown in the other studies (Palliotti et al. 2010 and Tittmann et al. 2013), one week after treatment in the VG-sprayed leaves a large reduction in leaf A and gs, which continued over the following 60 days with peak reductions compared with C was observed. Moreover, it's possible to show the positive correlation ($R^2 = 0.956$) between assimilation rate (A) and stomatal conductance (gs) identified in gas exchange data leaves (Fig. 18). Post-veraison the effect on stomatal closure was reduced in part, although E were lower than the control even late in the season in agreement with Palliotti et al. (2010). The depression of traspiration after VG application resulted in a significant increase in WUEi in VG-treated relative to C vines. Our results are confirmed by other studies: Sangiovese and Ciliegiolo leaves showed a smaller decrease in WUEi during the season in response to application of VG (Palliotti et al. 2010 and 2013). Falanghina also showed a significant reduction in WUEi for the VG treatment after application (Fig. 17B).

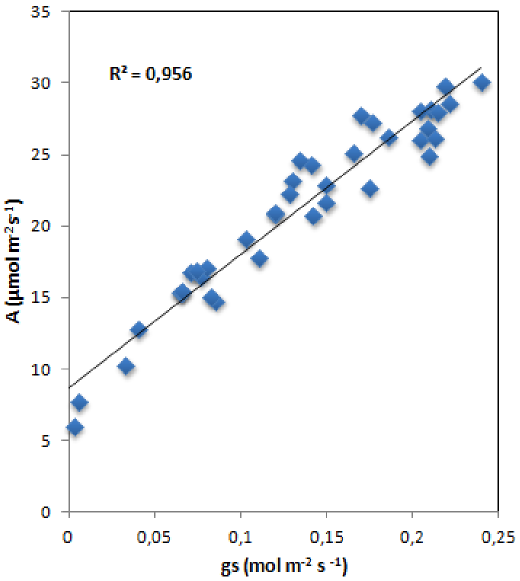

Figure 18 - Correlation between assimilation rate (A) and stomatal conductance (gs) calculated on Aglianico leaves sprayed with antitranspirant Vapor Gard® (VG) at 2% or left unsprayed (Control) with or without bunch thinning (BT).

For chlorophyll fluorescence parameters, the Fv'/Fm' ratio measured in both primary and lateral leaves did not show any difference among treatments (Fig. 19-20). Fv'/Fm' ratios in both treatments in 2013 on Aglianico leaves never dropped below 0.40, suggesting no significant photo-inhibition, although T leaves showed occasionally higher values later in the season (Fig. 19a), vines showed a similar pattern in 2014 year (Fig. 19B).

Same trend in 2013 and 2014 years on Falanghina leaves Fv'/Fm' ratios in both treatments never dropped below 0.41, suggesting no significant photo-inhibition, although T leaves showed occasionally higher values later in the season (Fig. 20 A-B). The Fv'/Fm' ratio was not modified between treated and Control vines, emphasizing that photoinhibition did not occur at the PSII complex.

The significant improvement of intrinsic WUEi, since VG application until the final stage of ripening, indicates a lower water loss through stomata for a similar carbon gain. This behavior occurred because the limitation in stomatal conductance of H_2O was proportionally higher than the depression of its assimilation rate according to Palliotti et al. 2013.

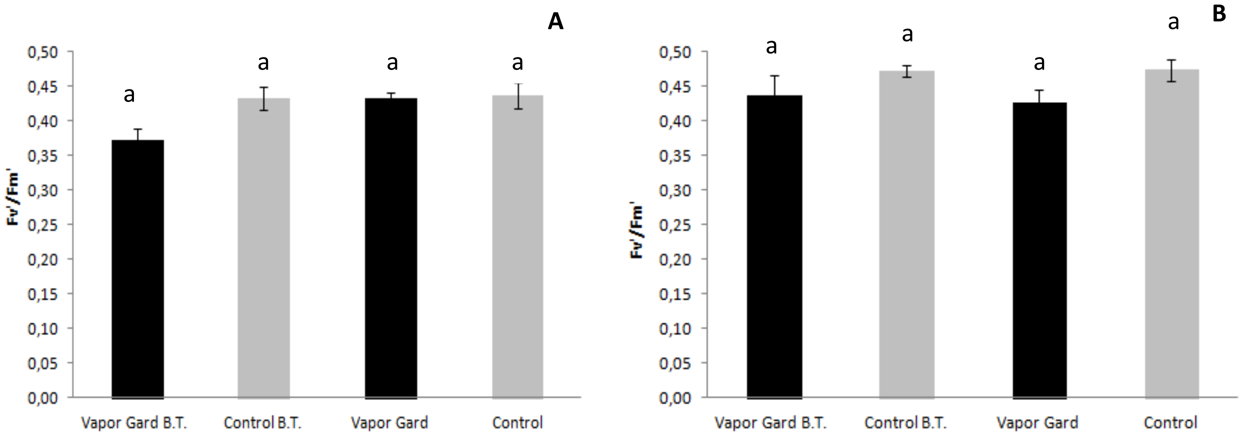

Figure 19 - Maximal photochemical efficiency of PSII in a light adapted leaf (Fv'/Fm') recorded in 2013 (A) and 2014 (B) on median primary and lateral leaves of Aglianico vines sprayed twice with antitranspirant Vapor Gard (VG) at 2% or untreated control. Data are mean ± SE. Same letter indicates not significant differences at Duncan post hoc test ($p<0.05$).

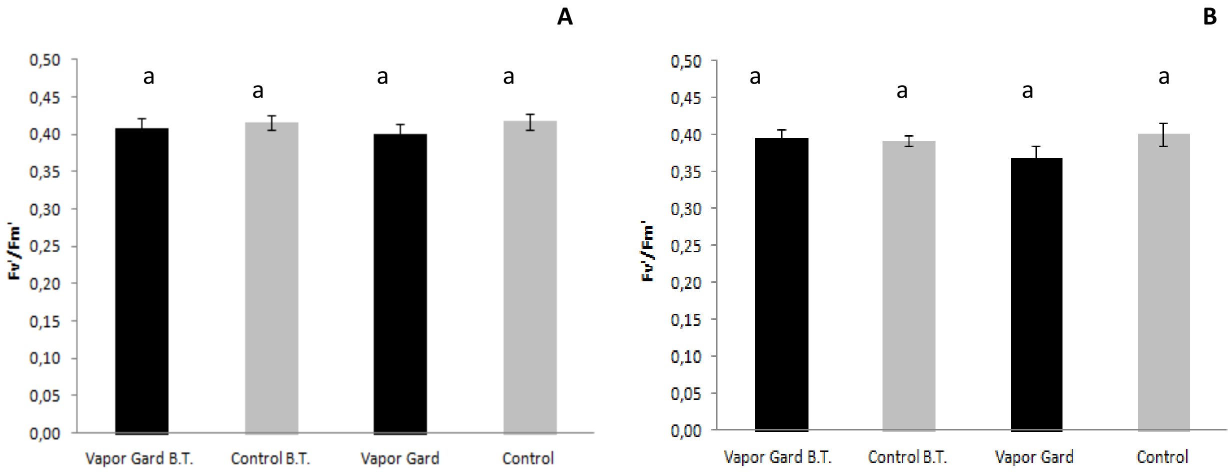

Figure 20 - Maximal photochemical efficiency of PSII (Fv'/Fm') recorded in 2013 (A) and 2014 (B) on median primary and lateral leaves of Falanghina vines sprayed twice with antitranspirant Vapor Gard (VG) at 2% or untreated control. Data are mean ± SE. Same letter indicates not significant differences at Duncan post hoc test ($p<0.05$).

Moreover, leaf temperature was significantly modified by the VG treatment. It's well-known that as stomata close under water deficits, leaf temperature increases. From the thermal image (Fig. 21) is clear that plants of the rows treated with Vapor Gard have a higher leaf temperature as a consequence of their reduced stomatal conductance. Traditional methods of measuring stomatal conductance (using porometers or infrared gas analysers) are time-consuming, labour-intensive, and only give spot measurements. Leaf or canopy temperatures can be used as an indicator of stomatal closure and indirectly of plant stress. Thermal imaging systems allow rapid and non-invasive collection of data. They may reveal spatial heterogeneity within or between leaves, and can be used repeatedly on the same leaves to monitor responses over time, without affecting the natural behaviour of the leaves. The nature of grapevine trellises, with plentiful leaves that are close to vertical exposure, means that this crop may be particularly suited to monitoring with a thermal imager which can be carried along the rows. The development of thermal imaging and the associated image analysis software has overcome the problems experienced by researchers using infrared thermometry with regard to the difficulty of separating leaf and non-lea (soil, sky, bark, etc.) temperatures. While application of thermal imaging is more straightforward in the laboratory (Chaerle et al., 1999; Lindenthal et al., 2005), researchers have also applied the technique to the field (Jones et al., 2002; Cohen et al., 2005). Nonetheless, rigorous testing of thermal imaging against more traditional physiological techniques under field conditions is still required for different types of crops. Indices that relate leaf or canopy temperatures to the temperatures of selected reference surfaces allow for variation in air temperature, radiation, and wind speed, thus removing the effect of environmental variation so as to indicate increases or decreases in stomatal conductance (Jones, 1999). Our thermal image derived from our study and the corresponding digital image showed as the VG treated vines presents higher temperature compared with control vines (fig. 21). The area of interest on the thermal image is outlined. The treated vines had leaf temperatures closer to the maximum detected equal to 36.6 °C, while leaves temperature of not treated vines are closer to the minimum detected equal to 28 °C.

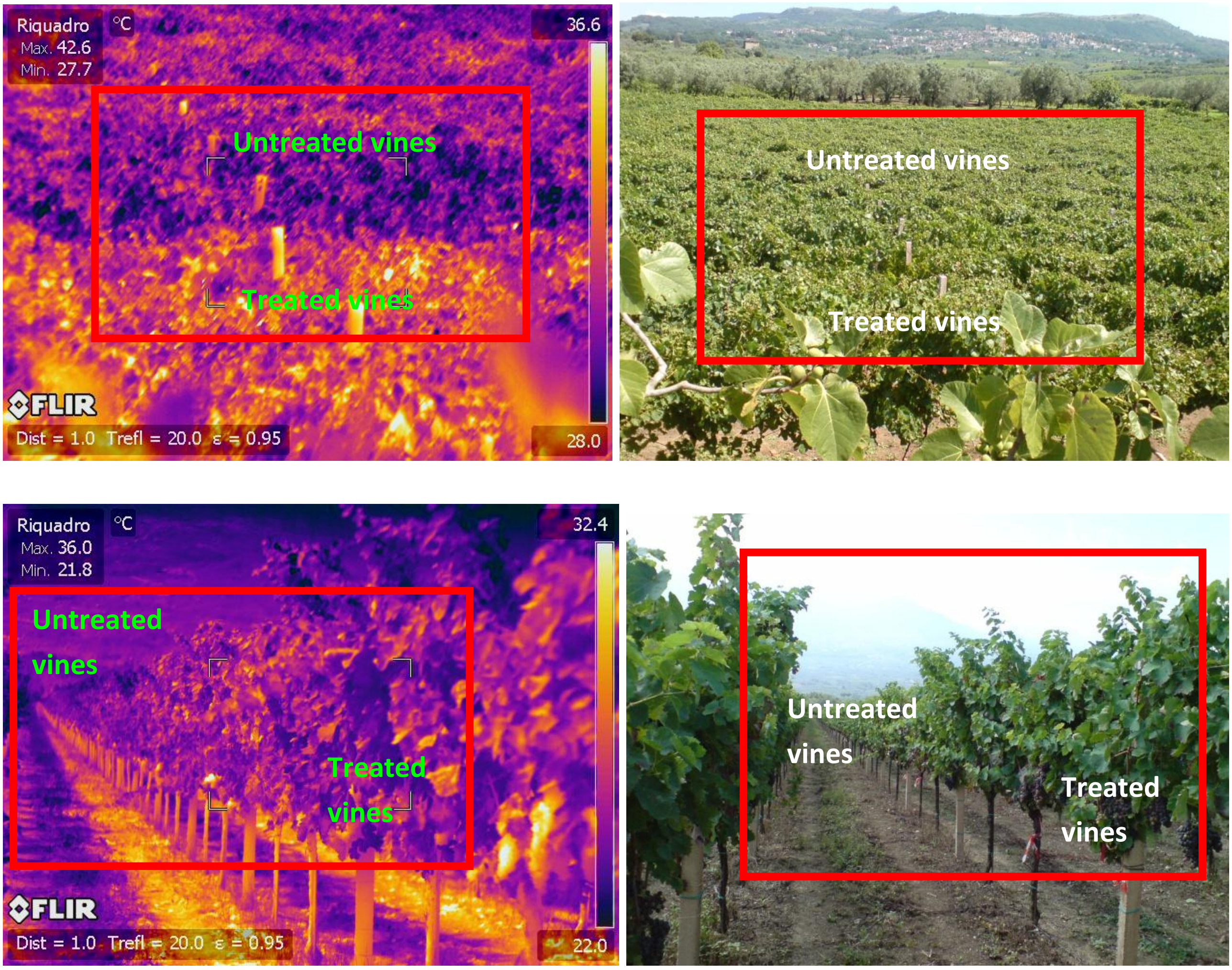

Figure 21 - Thermal image and the corresponding digital image. The area of interest on the thermal image is outlined. The box includes treated and untreated thesis with VG antitraspirant, characterized by different colors: yellow and orange = treated vines and purple and blue = untreated vines.

The fact that the film-forming VG exerts a physical barrier to gas exchange, thus hampering the CO_2 entering the stomata and the water vapor leaving the stomata, was found almost 40 years ago on Vicia faba by Davenport et al. (1972), who also noted that under the transparent film the stomata were more open. Scanning electron micrographs on bean plants (Iriti et al. 2009) confirmed these results. Moreover, in peach, midday leaf water potential increased after an antitranspirant application as compared to unsprayed plants (Davenport et al. 1972). Thus, maintenance of high moisture of the leaf tissue in conjunction with possible effects of light reflectance might explain why treated leaves did not heat up significantly, in agreement with findings in a tropical plant using the same compound (Moftah and Al- Humaid 2005). In terms of light reflectance, VG behaves differently than kaolin-based foliar reflectants, which have proven to cause a significant reduction of leaf and/or berry temperature (Moftah and Al-Humaid 2005, Rosati 2007, Shellie and King 2013), especially under limiting water supply. The significant improvement of intrinsic WUEi, extending from the time of VG application until the final stage of ripening, indicates a lower water loss through stomata for a similar carbon gain. This behavior occurred because the limitation in stomatal conductance of H_2O was proportionally higher than the depression of its assimilation rate.

A significant source limitation following VG spraying has been previously assessed in different species (Iriti et al. 2009, Francini et al. 2011), including grapevine (Palliotti et al. 2010) and, quite remarkably, the above source limitation is reached without modifying the vine leaf-to-fruit ratio or the cluster microclimate during ripening. This strategy of canopy management, applied late in the season, has been effective in reducing the pace of sugar accumulation in the berry, as compared to control vines, scoring a -1.2 Brix at harvest and lowering the alcohol content in the resulting wines by -1% vol. It can be recommended as a valuable cultural practice in viticultural areas where berry ripening takes place early during the hottest part of the season Palliotti et al. 2013 and 2014.

From veraison to harvest we monitored average berry weight (g), total soluble solids (TSS), pH and titratable acidity (TA) for both years 2013 and 2014 and for both cultivars Aglianico and Falanghina. As reported in Figures from 22 to 29 , it is possible to see how these parameters evolve during the season and to appreciate the significant differences both in berry weight and TSS between treatments. In the year 2013 any significant differences we can observe in 100 Aglianico berry weight, the second year of the study 100 berry weight is lower for fruit from Control vines after application that Vapor Gard treatment vines (Fig. 22B). Falanghina berry weight was not significantly different between treatments in both years 2013 and 2014 (Fig. 23). Finally, at harvest time, berry weight is not changed after VG treatment according to other authors (Palliotti et al., 2010).

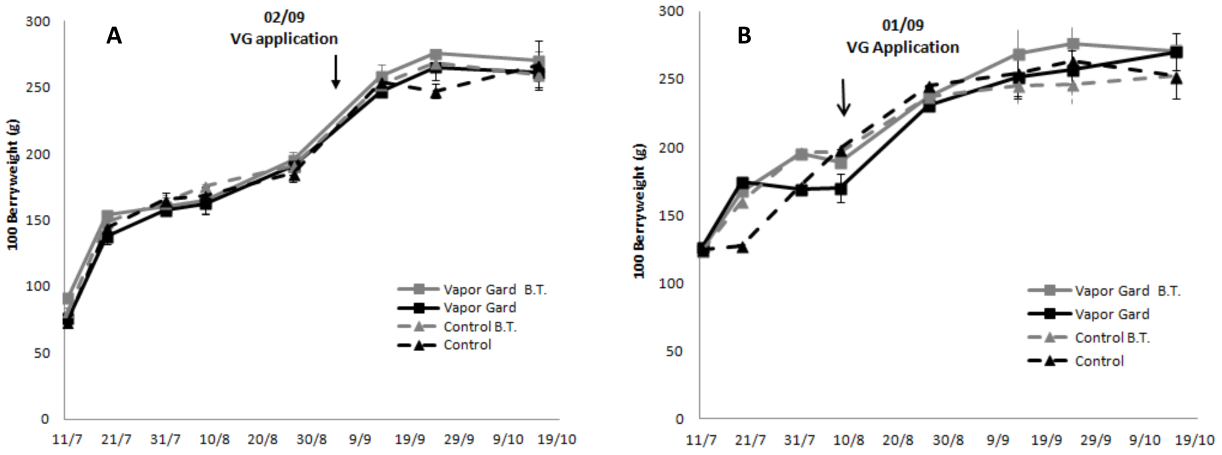

Figure 22 - 100 Berry weight measured in Aglianico vines in 2013 (A) and 2014 (B). Data are mean ± SE.

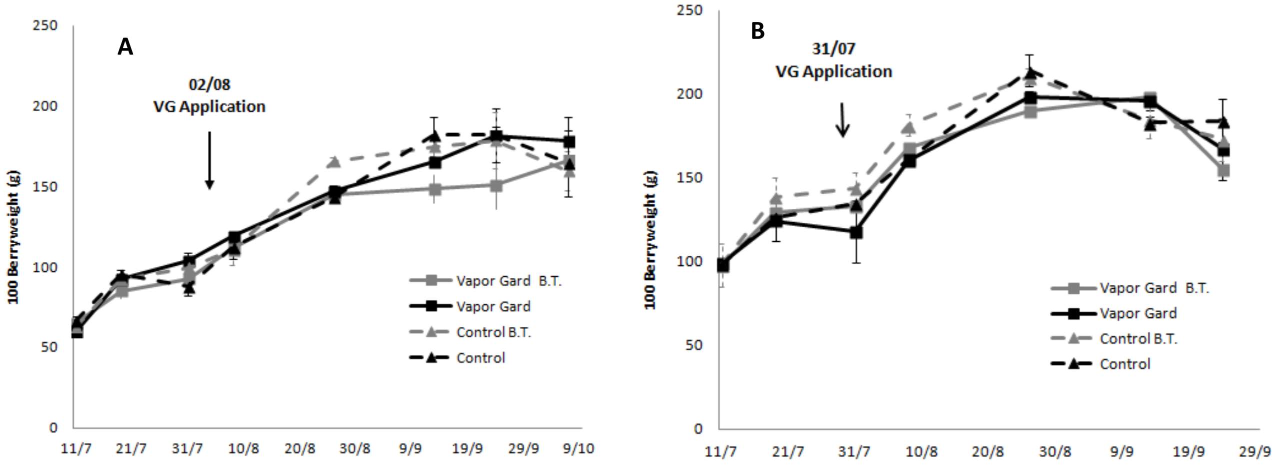

Figure 23 - 100 Berry weight measured in Falanghina vines in 2013 (A) and 2014 (B). Data are mean ± SE.

Sugar accumulation in the berry showed that, regardless of VG treatment, the accumulation is slower about 15 days after VG treatment in accordance with other authors (Palliotti et al. 2010) (Figures 24-25). In both years in Aglianico cultivar we can observe lower sugar accumulation at harvest time as 19.10 *vs* 21.9 °Brix VG bunch thinning vines and control bunch thinning vines respectively. Same trend we can observe for treatment without bunch thinning: 19.00 *vs* 21.10 °Brix for VG treated vines and Control vines. In total, in fact, we can demonstrate that after Vapor Gard teatment we have a different 2.8 °Brix for bunch thinning vines and 2.1 °Brix for vines without bunch thinning (Fig. 24). These values are confirmed with values found in other works (Palliotti et al. 2013 and 2010; Tittman et. al 2010). Same trend and values we can observed for Falanghina cultivar: in the year 2013 for bunch thinning vines the reduction amounts to 0.8 °Brix with values equal to 22.28 *vs* 23.12 °Brix for Vapor Gard and Control vines respectively and 0.9 °Brix for vines without bunch thinning. Same trend in the year 2014 with values more marked: 1.8 °Brix for bunch thinning vines and 2.7 °Brix for vines without bunch thinning (Fig. 25). The reduction in TSS found in VG-treated vines may be linked to a reduction in canopy photosynthetic capacity and/or limitation in sugar translocation from leaves to berries, according to other work of Palliotti et al. (2008). Between VG application and harvest, the rate of TSS accumulation in the berries decreased (Figures 24-25).

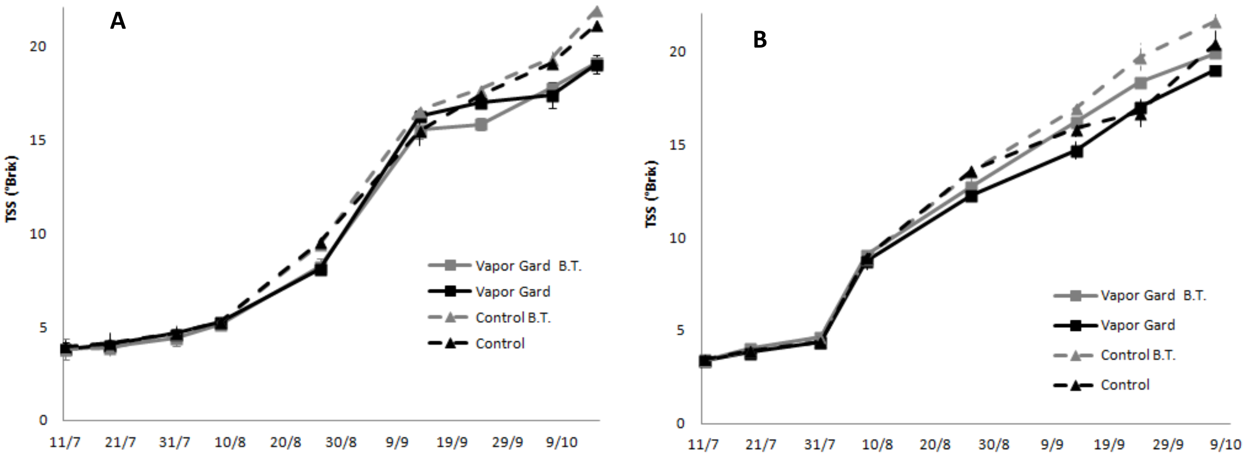

Figure 24 - Total soluble solids (TSS) measured in Aglianico vines in 2013 (A) and 2014 (B). Data are mean ± SE.

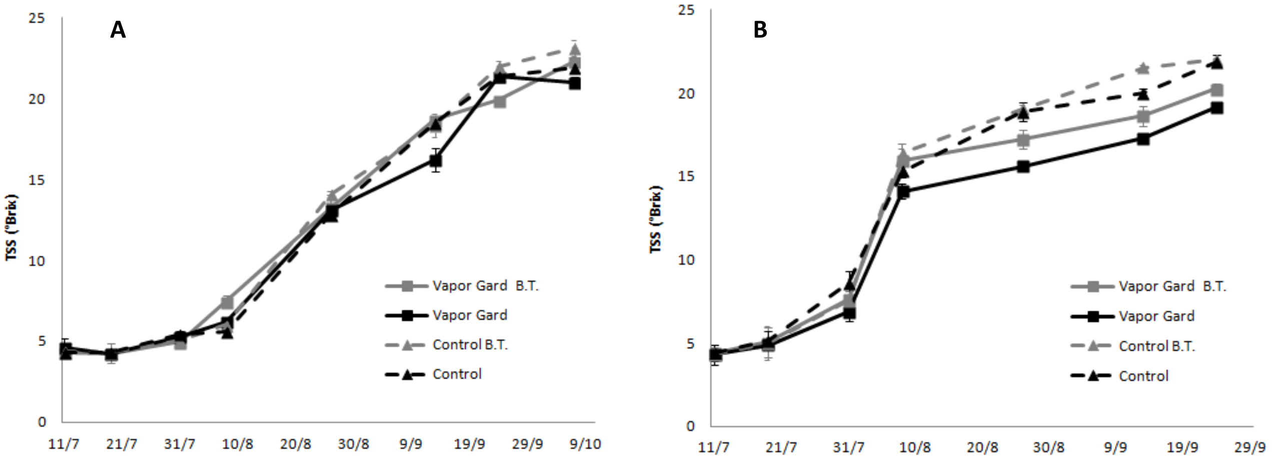

Figure 25 - Total soluble solids (TSS) measured in Falanghina vines in 2013 (A) and 2014 (B). Data are mean ± SE.

Aglianico and Falanghina TA and pH were unaffected by treatments (Figures 26-29). As can be seen in the figures, during the growing season, are not shown significant differences between treatments. Vapor Gard doesn't influence TA and pH of the berries as reported by other authors. At harvest time average Aglianico pH was 2.88 in the year 2013 and 2.89 in 2014, with no difference between treated and no treated vines. Same trend we can observe for Falanghina cv: 3.04 was the average pH registred in the 2013 year and 2.97 in the year 2014. Similarly, no statistical difference was found in titratable acidity between treatments, whereas average TA in the VG-treated vines were around 11.15 g/L of tartaric acid compared to Control vines 10.70 g/L of tartaric acid in Aglianico in 2013 year. Same trend for second year of study. In Falanghina cv the average data was 9.10 g/L of tartaric acid in the 2013 and 7.89 g/L of tartaric acid in the 2014 year without significant difference between Control and treated vines.

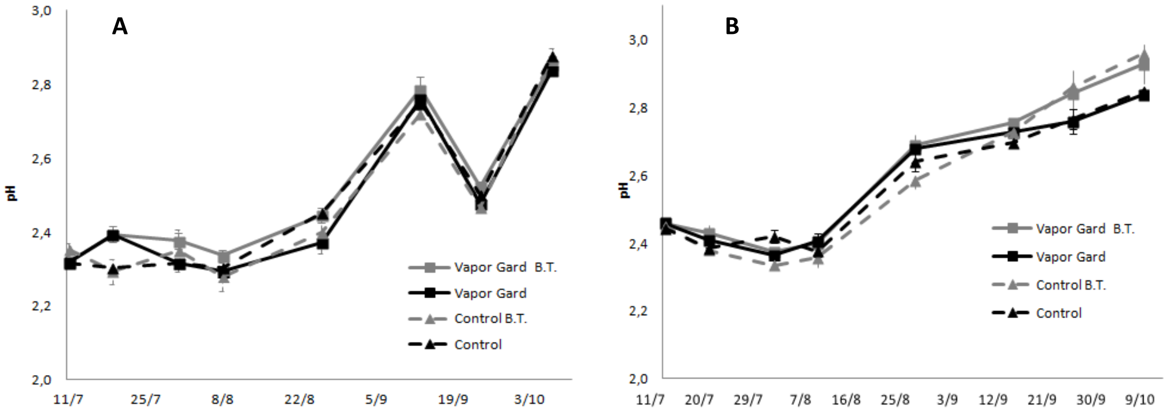

Figure 26 - pH measured in Aglianico vines in 2013 (A) and 2014 (B). Data are mean ± SE.

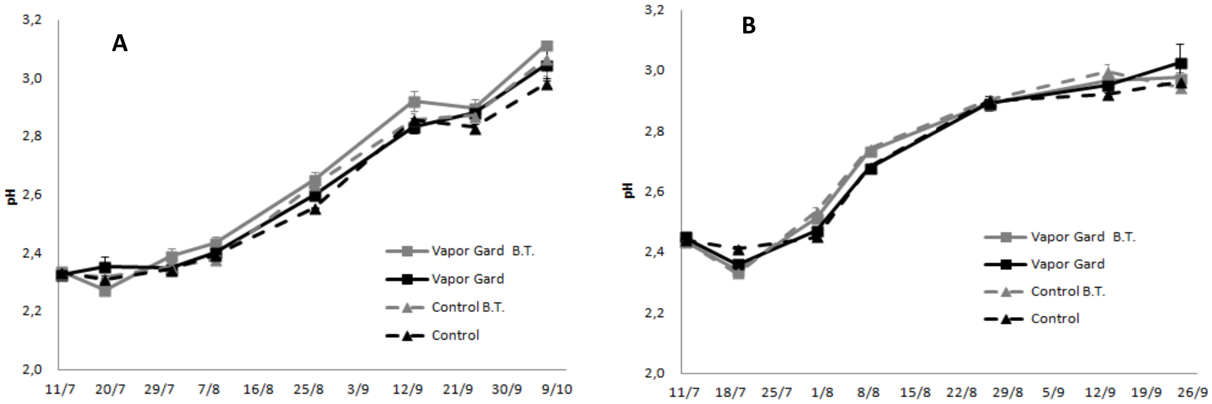

Figure 27 - pH measured in Falanghina vines in 2013 (A) and 2014 (B). Data are mean ± SE.

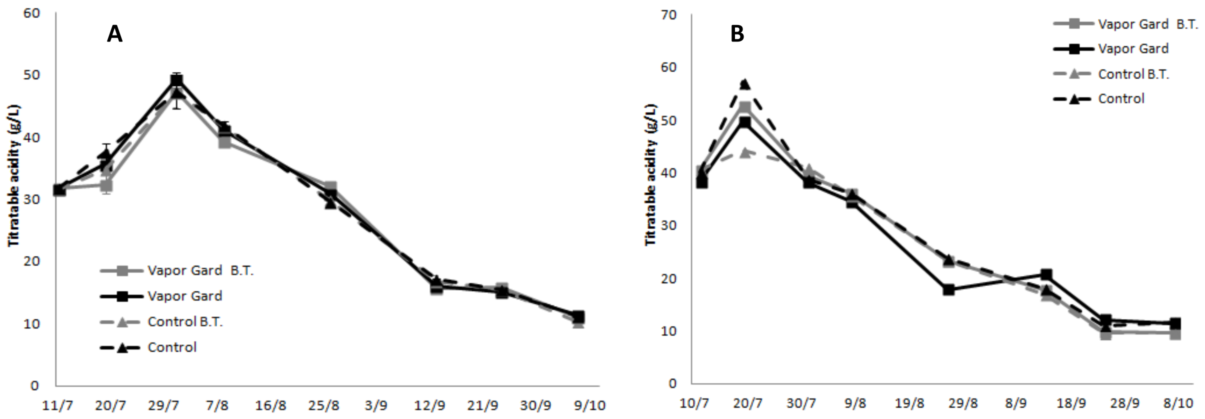

Figure 28 - Titratable acidity (TA) measured in Aglianico vines in 2013 (A) and 2014 (B). Data are mean ± SE.

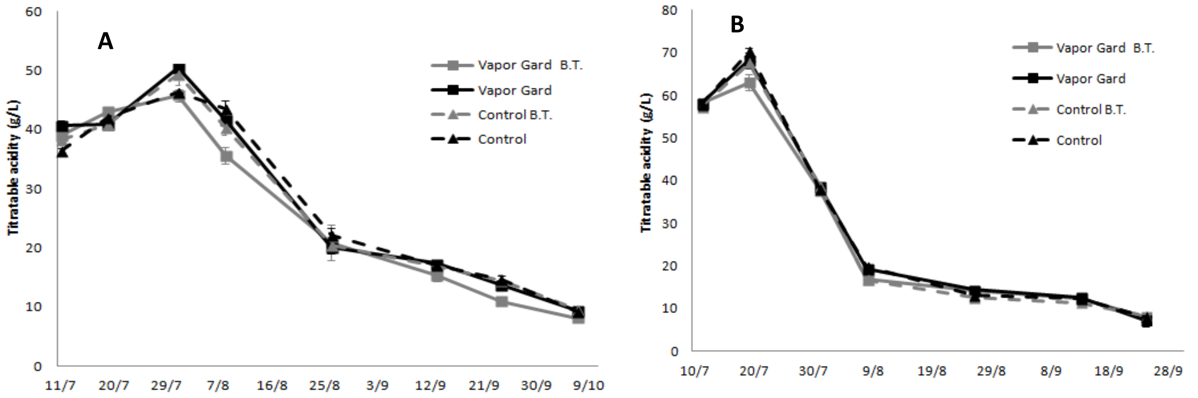

Figure 29 - Titratable acidity (TA) measured in Falanghina vines in 2013 (A) and 2014 (B). Data are mean ± SE.

In 2013 and 2014 year also, at harvest, as expected, bunch-thinned Aglianico vines had lower yield and lower bunch number per vine than controls. VG applied at veraison did not affect yield per vine or average bunch and berry weight (Table 1) as shown by Palliotti et al., (2013). TSS was significantly lower in VG treated vines compared to control but no differences were found when bunch thinning was also applied. Control vines showed an average berry weight at harvest of 2.67 g *vs* 2.61 g of Vapor Gard berry. Same trend for second year 2.52 *vs* 2.70 g for average berry weight. °Brix berry showed a significant difference between control and treated vines: 21.1 *vs* 19.0 °Brix respectively for Control and VG treatment in the year 2013 for Aglianico and 20.4 *vs* 19.0 °Brix respectively for Control and VG treatment in the year 2014. Other authors (Palliotti et al. 2012; Carnevali and Falcetti 2012; Lazzini et al. 2012; Tittmann et al. 2013) obtained similar results with significant reduction in TSS and, subsequently in alcohol, when VG was applied. Some statistical differences between treatments were also observed for juice TA (g/L) in both year 2013 and 2014. VG applied at veraison did not affect juice pH in Aglianico cultivar.

Table 1 - Yield components, bunch morphology and grape composition recorded in Aglianico and vines treated (VG) or not (Control) with or without bunch thinning (BT) in both year 2013 and 2014. For each parameter, values with the same letter are not significantly different by Duncan's *post hoc* test ($p < 0.05$).

	2013				2014			
Parameters	Control	Vapor Gard	Control BT	Vapor Gard BT	Control	Vapor Gard	Control BT	Vapor Gard BT
Yield/vine (Kg)	7.6 b	8.5 b	6.2 a	5.4 a	7.6 b	7.1 b	4.8 a	4.6 a
Bunches/vine	24.8 b	27.3 b	14.9 a	11.6 a	21.3 b	20.0 b	11.5 a	11.9 a
Average berry weight (g)	2.67 a	2.61 a	2.60 a	2.71 a	2.52 a	2.70 a	2.52 a	2.71 a
°Brix berry	21.1 a	19.0 b	21.9 a	19.1 b	20.4 bc	19.0 a	21.6 c	19.9 ab
Juice pH	2.88 a	2.84 a	2.87 a	2.95 a	2.85 a	2.84 a	2.96 a	2.93 a
Juice TA (g/L of tartaric acid)	11.17 ab	11.37 a	10.23 c	10.93 b	11.61 b	11.40 b	9.67 a	9.53 a

In Falanghina differences were observed for same parameters measured at harvest (Table 2). °Brix berry was significantly different. Bunch-thinned Falanghina vines had lower yield and lower bunch number per vine than controls as expected. Berries from Vapor Gard vines were significantly lowest in °Brix.

Regardless of both year, VG applied in veraison above the cluster zone did not affect yield per vine and bunches/vine, while average berry weight didn't show statistically significant differences (Table 2).

Control vines showed an average berry weight at harvest of 1.64 g *vs* 1.77 g of Vapor Gard berry. Same trend for second year 1.84 *vs* 1.67 g for average berry weight. No statistically significant difference was found between the average weights of the berry. Brix berry showed, instead, a significant difference between control and treated vines: 21.9 *vs* 21.0 °Brix respectively for Control and VG treatment in the year 2013 for Falanghina and 21.9 *vs* 19.2 °Brix respectively for Control and VG treatment in the year 2014. Bunch thinning treatment showed same trend with high content of sugar in control berries respect VG berries in both years (Table 2).

Table 2 - Yield components, bunch morphology and grape composition recorded in Falanghina and vines treated (VG) or not (Control) with or without bunch thinning (BT) in both year 2013 and 2014. For each parameter, values with the same letter are not significantly different by Duncan's *post hoc* test (p <0.05).

	2013				2014			
Parameters	Control	Vapor Gard	Control BT	Vapor Gard BT	Control	Vapor Gard	Control BT	Vapor Gard BT
Yield/vine (Kg)	6.1 b	6.3 b	5.5 a	5.4 a	6.4 b	6.1 b	4.7 a	3.8 a
Bunches/vine	17.9 b	17.7 b	15.1 a	15.0 a	20.0 b	21.7 b	16.6 a	15.1 a
Average berry weight (g)	1.64 ab	1.77 b	1.60 a	1.66 ab	1.84 b	1.67 ab	1.73 ab	1.55 a
°Brix berry	21.9 b	21.0 a	23.1 c	22.3 bc	21.9 b	19.2 a	22.1 b	20.3 a
Juice pH	2.98 a	3.04 ab	3.06 ab	3.11 b	2.96 a	3.03 a	2.94 a	2.97 a
Juice TA (g/L of tartaric acid)	9.16 a	9.50 a	9.60 b	8.16 a	7.96 ab	7.33 a	8.23 b	8.06 ab

At harvest time of Aglianico samples collected for analysis on the index of phenolic maturity (Glories, 1982). Extractable anthocyanins Glories (pH 1) differed significantly between the two treatments (Vapor Gard and Control vines): Vapor Gard shows more content of Extractable anthocyanins (pH 1) 1044 mg/l than Control vines 996 mg/l in the year 2013 without bunch thinning treatment (Table 3) and 1124 vs 1224 mg/l for Control and Vapor Gard respectively in the year 2014. Same results we can observe in both years for treatment with bunch thinning. While extractable anthocyanins (pH 3.2) and total phenolics (D.O.280) were similar between control and VG vines with or without bunch thinning (Table 3) in both years, without statistically significant differences.

Table 3 - Extractable anthocyanins and total phenolics recorded in Aglianico and vines treated (VG) or not (Control) with or without bunch thinning (BT) in both year 2013 and 2014. For each parameter, values with the same letter are not significantly different by Duncan's *post hoc* test (*p* <0.05).

		2013				2014			
Unit of measure	Parameters	Control	Vapor Gard	Control BT	Vapor Gard BT	Control	Vapor Gard	Control BT	Vapor Gard BT
mg/l	Extractable anthocyanins Glories (pH 1)	996 a	1044 b	992 a	1108 b	1124 a	1224 b	1228 b	1476 c
mg/l	Extractable anthocyanins Glories (pH 3.2)	902 a	912 a	910 a	923 a	928 a	952 a	964 a	904 a
	Total phenolics (D.O.280)	75 a	64.5 a	69 a	75.3 a	60.8 a	65.9 a	62.0 a	64.3 a

After microvinification and wines analyses we observed that alcohol content in Aglianico wine was affected by VG treatments with significantly lower alcohol percentage measured in both VG treatments (with and without bunch thinning) compared to the respective controls (Table 4). In the year 2013 it was observed the value of alcohol content wine of Vapor Gard treatment: 11.0 *vs* 12.3 for treatment without bunch thinning and 10.9 *vs* 12.9 for treatment with bunch thinning. Similarly, statistical difference was found in the second year of study (2014): 11.0 *vs* 12.5 (VG and C vines respectively) for treatment without bunch thinning and 10.6 *vs* 12.7 (VG and C vines respectively) for treatment with bunch thinning. Total phenolics and total anthocyanins were similar (Table 4), without statistically significant differences between control and VG vines even when bunch thinning was also applied, Palliotti et al. (2013) reported similar observations.

Table 4 - Wine composition recorded in Aglianico cultivar treated (VG) or not (Control) with or without bunch thinning (BT) in both year 2013 and 2014. For each parameter, values with the same letter are not significantly different by Duncan's post hoc test (p <0.05).

	2013				2014			
Parameters	Control	Vapor Gard	Control BT	Vapor Gard BT	Control	Vapor Gard	Control BT	Vapor Gard BT
Alcohol (%)	12.3 b	11.0 a	12.9 b	10.9 a	12.5 b	11.0 a	12.7 b	10.6 a
Total anthocyanins (mg/kg)	510 a	490 a	526 a	520 a	181 a	163 a	166 a	197 a
Total phenolics (mg/Kg)	1555 a	1467 a	1720 a	1601 a	1719 a	1779 a	1797 a	1814 a

VG applications on Falanghina vines did not significantly modify wine composition pattern at harvest except for a higher alcohol (%) content, concentration in C vines in 2013 was 13.9 *vs* 13.4 in VG vines without bunch thinning and 14.4 *vs* 13.1 % alcohol (C and VG vines respectively) with bunch thinning treatment (Table 5). Same results we can report for second year of study: 13.2 *vs* 11.5 % alcohol (C and VG vines respectively) for treatment without bunch thinning and 13.5 *vs* 12.1 (C and VG vines respectively) for treatment with bunch thinning. To highlight that the thinned thesis always showed an alcohol content greater than not thinned thesis. Total phenols were similar between control and VG vines also when bunch thinning was also applied.

Table 5 - Wine composition recorded in Falanghina cultivar treated (VG) or not (Control) with or without bunch thinning (BT) in both year 2013 and 2014. For each parameter, values with the same letter are not significantly different by Duncan's post hoc test (P <0.05).

	2013				2014			
Parameters	Control	Vapor Gard	Control BT	Vapor Gard BT	Control	Vapor Gard	Control BT	Vapor Gard BT
Alcohol (%)	13.9 ab	13.4 a	14.4 b	13.1 a	13.2 b	11.5 a	13.5 b	12.1 a
Total anthocyanins (mg/kg)	/	/	/	/	/	/	/	/
Total phenolics (mg/Kg)	1085 a	1111 a	1118 a	1021 a	950 a	918 a	1039 a	1040 a

Phenol composition is an important aspect in high quality red wines. Phenols are responsible for astringency and bitterness (Fischer & Noble, 1994), and play a role in colour stability (Robinson et al. 1966). The phenolic profile of a wine has been shown to be influenced by different viticultural practices (Price et al. 1995; Reynolds et al. 1994; Yokotsuka et al. 1999; Zoecklein et al. 1995), and different enological techniques (Sims & Bates, 1994; Wightman et al. 1997; Zoecklein et al. 1995). The variety (Goldberg et al. 1998), vintage (Brossaud et al. 1999; Yokotsuka et al. 1999), and region where the grapes are grown (Brossaud et al. 1999; Goldberg et al. 1998) all affect the phenolic composition of the wine. Anti traspirant effects didn't afflict the total phenolic composition demosting in this way that it's possible to concept this method as a better way for reducing sugar and alcohol content without to influencing the quality of the wine product.

The amounts of wine aroma components can be influenced by various factors, amongst others the environment (climate, soil), grape variety, the degree of ripeness, fermentation conditions (pH, temperature, yeast flora), wine production (oenological methods, treatment substances) and aging (bottle maturation) of the wine.

After sensory analysis of the wines produced in two years of study is possible to detect the typical notes of Aglianico and Falanghina in both years 2013 and 2014 and on both cultivars. Aglianico wine products presents a good intensity and persistency and also good body and harmony; same results we can show second year of study on Aglianico wine (Fig. 30). In Aglianico wine we relevant notes of: phenol leather, good structure, acidity and typicality. Red fruits notes were presented during the wine tasting in both years 2013 and 2014 (Fig. 32). No significant difference was shown between the wines produced by treated grapes with antitraspirant and untreated grapes. The card characteristics of Falanghina cultivar shows that the vines produced by microvinification have a good intensity, harmony, overall and persistency in both years of study (Fig. 31). Falanghina wine reported after sensory analysis notes of floral citrus, good acidity, structure, tupicaly and sapid (Fig. 33). Also for white product wines we can report no significant differences between the wines produced by treated grapes with antitraspirant and untreated grapes.

The aroma of wine consists of 600 to 800 aroma compounds from which especially those, typical for the variety, are already present in the grapes. There are significant varietal differences between the aromagrams (‘fingerprint patterns’). Thus the amount of some flavour compounds (‘key substances’) shows typical dependence on the variety. Especially monoterpene compounds play an important role in the differentiation of wine varieties. We can show after this sensory analysises and wine tasting that the antitraspirant product does not affect the wine notes and their characteristic structure.

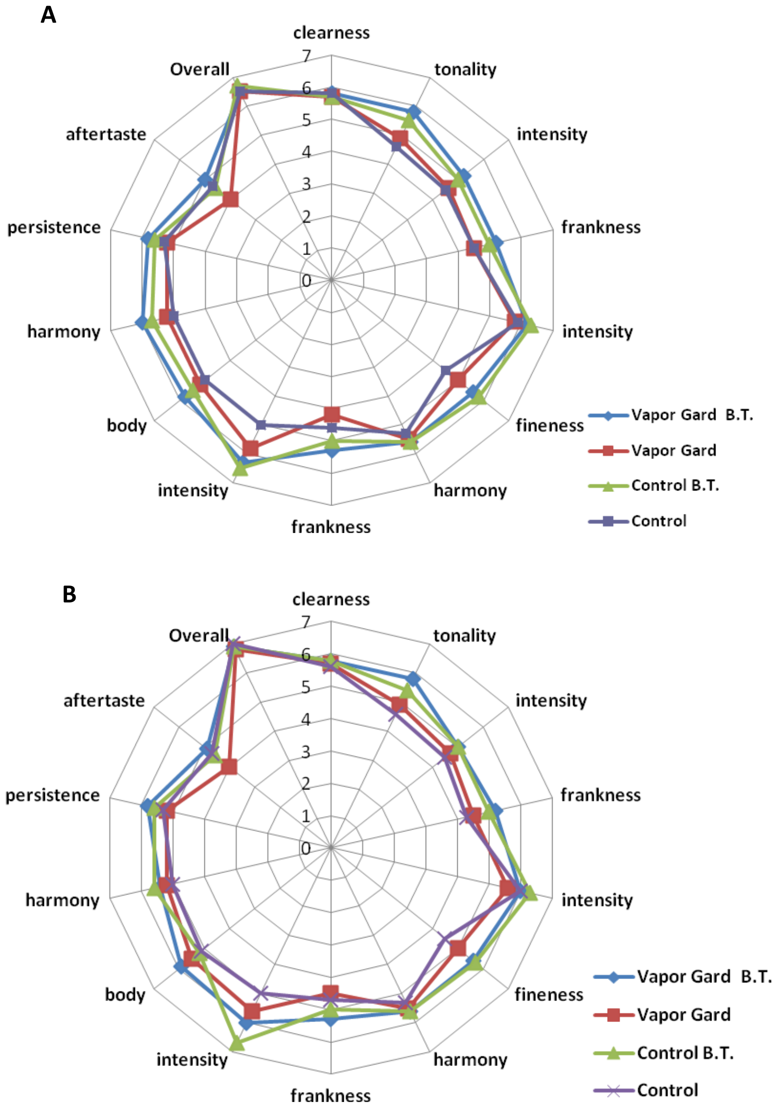

Figure 30 - Aroma compounds measured in Aglianico wine in 2013 (A) and 2014 (B).

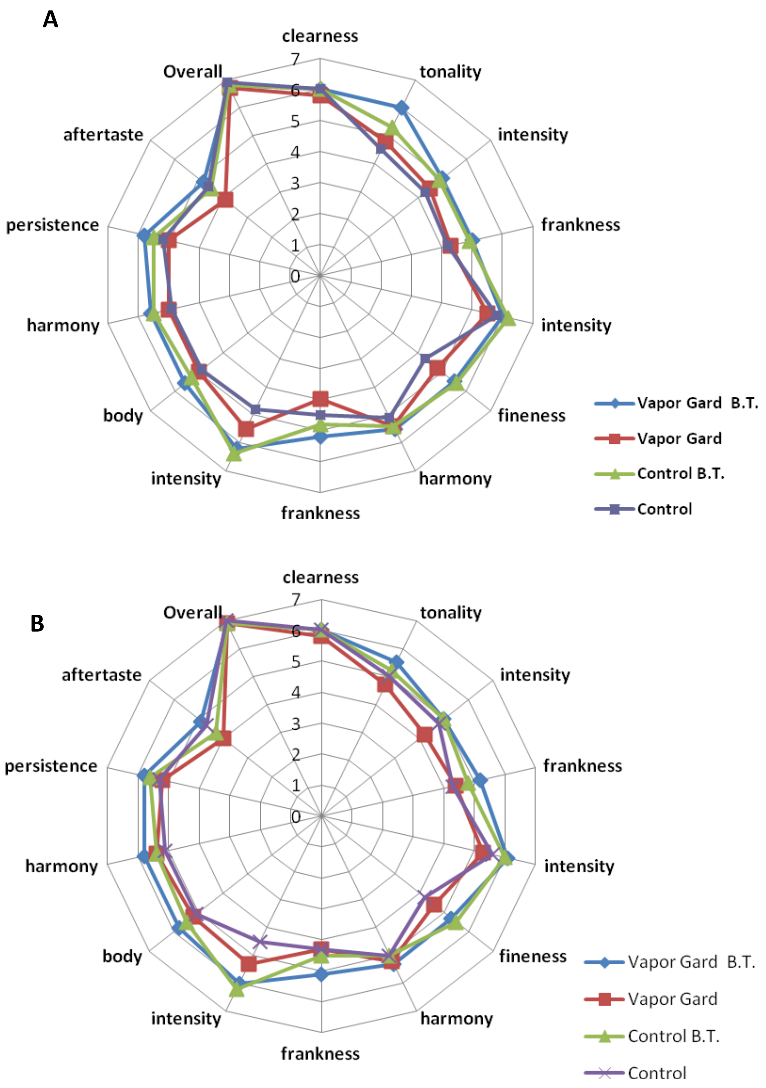

Figure 31 - Aroma compounds measured in Falanghina wine in 2013 (A) and 2014 (B).

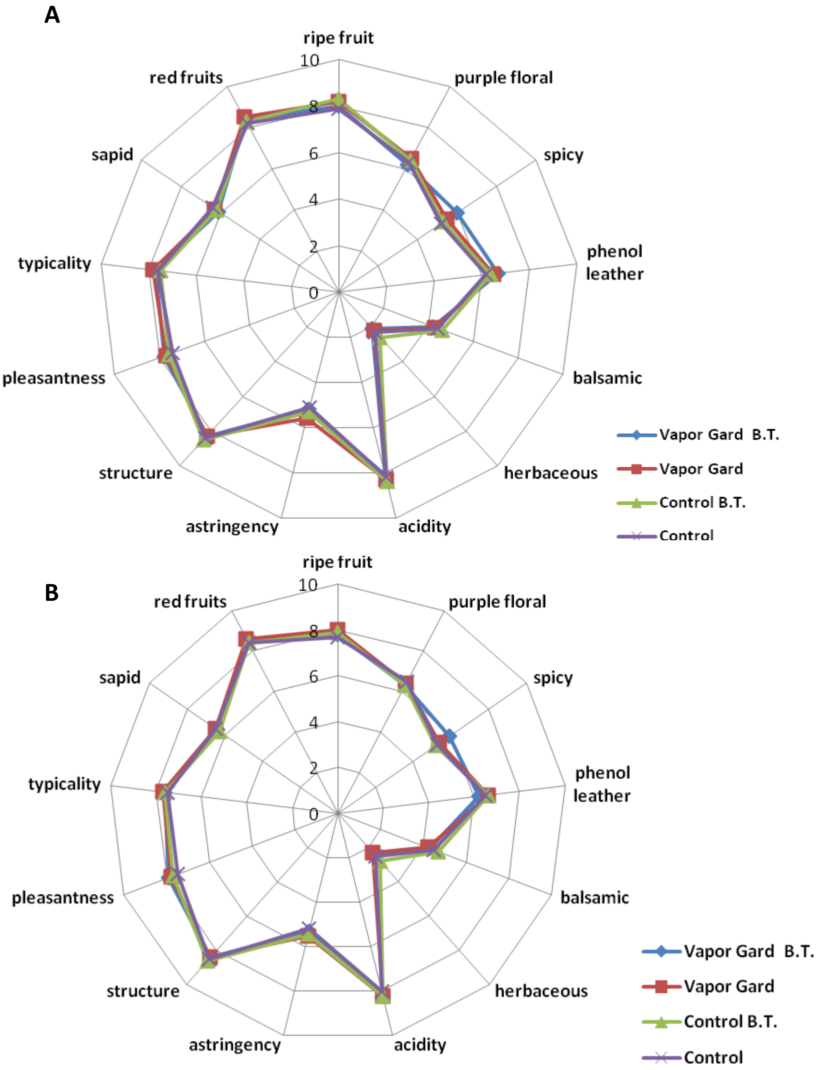

Figure 32 - Descriptive analysis aroma profile for Aglianico wine in 2013 (A) and 2014 (B).

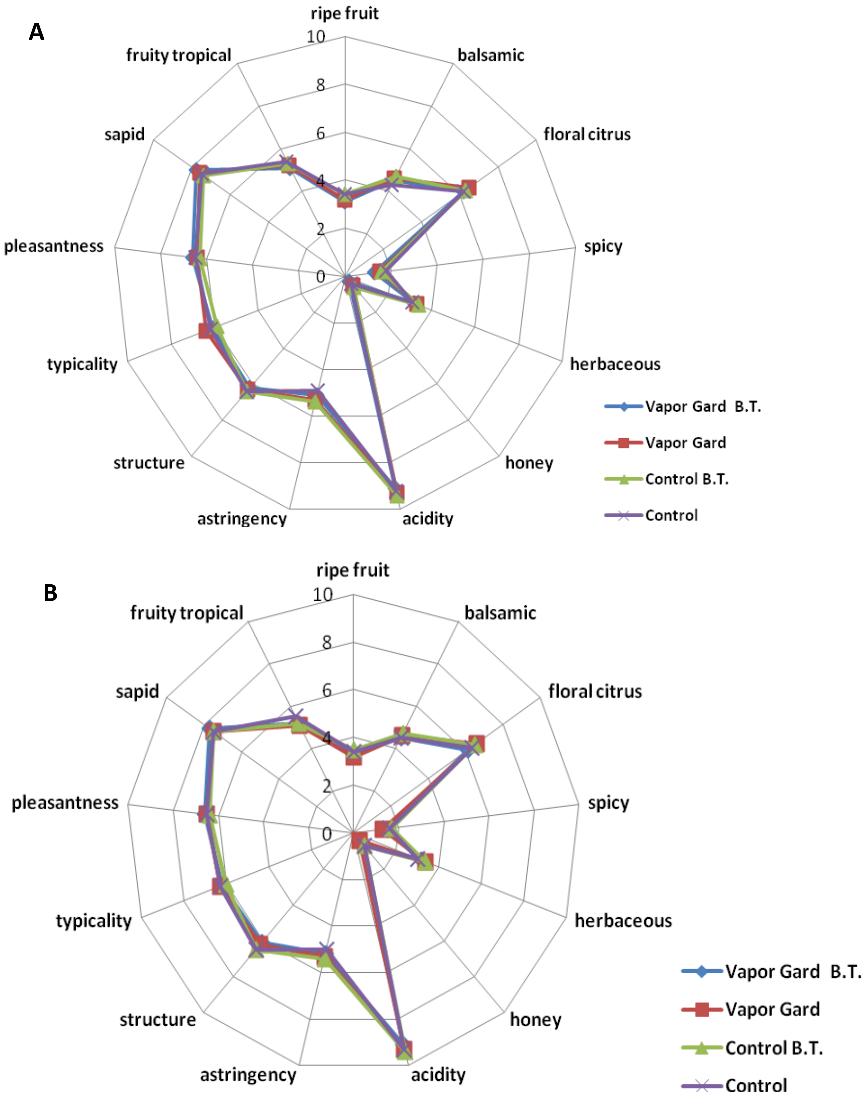

Figure 33 - Descriptive analysis aroma profile for Falanghina wine in 2013 (A) and 2014 (B).

Pruning weight was significantly reduced each years, 2013 and 2014, in the VG sprayed Aglianico and Falanghina vines as compared with C vines (Figures 34-35). In the year 2013 pruning weight measured after VG application was 3.8 Kg in the control and 2.9 Kg in the VG treated Aglianico vines. The bunch thinning treatment also showed differences in pruning weight: the control with BT was 3.2 Kg and the sprayed treatment 2.5 Kg in Aglianico vines (Fig. 34A). Same results with statistically significant differences between treated and control vines were recorded in the year 2014 for Aglianico (Fig. 34B). In line with the trend of Aglianico is also Falanghina cv: in the year 2013 pruning weight measured after VG application was 3.2 Kg in the control and 2.5 Kg in the VG treated Falanghina vines (Fig. 35A). The bunch thinning treatment also showed differences: the control with BT was 3.8 Kg and the sprayed treatment 2.9 Kg in Falanghina vines. Same results with statistically significant differences between treated and control vines were recorded in the year 2014 for Falanghina (Fig. 35B). Independently of the bunch thinning the vines treated show a lower pruning weight respect control vines (Fig. 34-35). Notably, lower pruning weight emphasise that vine ‘vigor’ was restrained by VG to the benefit of the ripening process, suggesting that this compound could be considered for applications aimed at controlling vigour while avoiding or limiting the counteracting effect of a smaller source potential, according to Palliotti et al. (2010 and 2013).

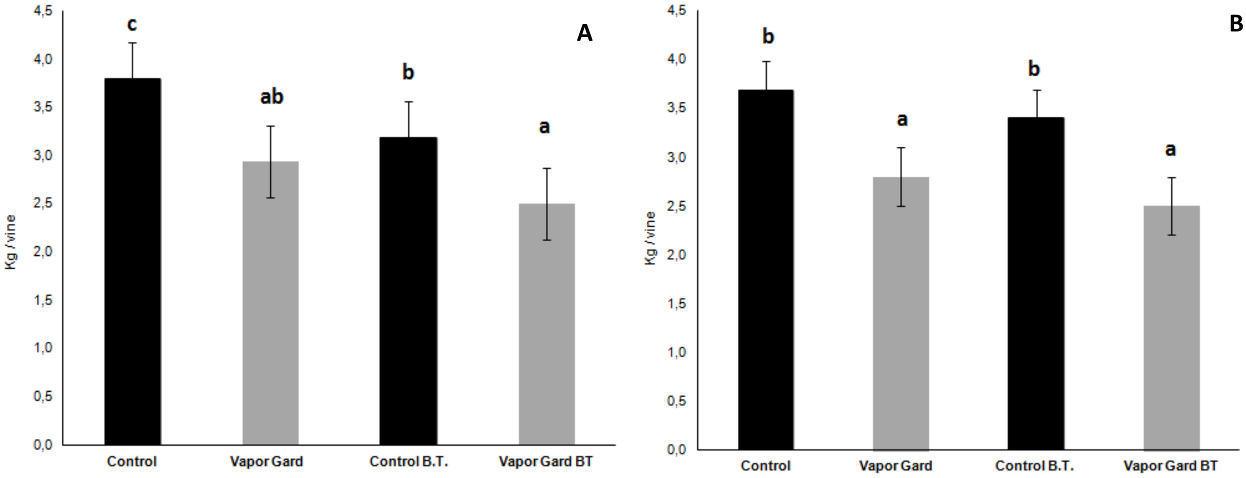

Figure 34 - Pruning weight/vine measured in Aglianico vines in 2013 (A) and 2014 (B). Data are mean ± SE. Same letter indicates not significant differences at Duncan post hoc test (p<0.05).

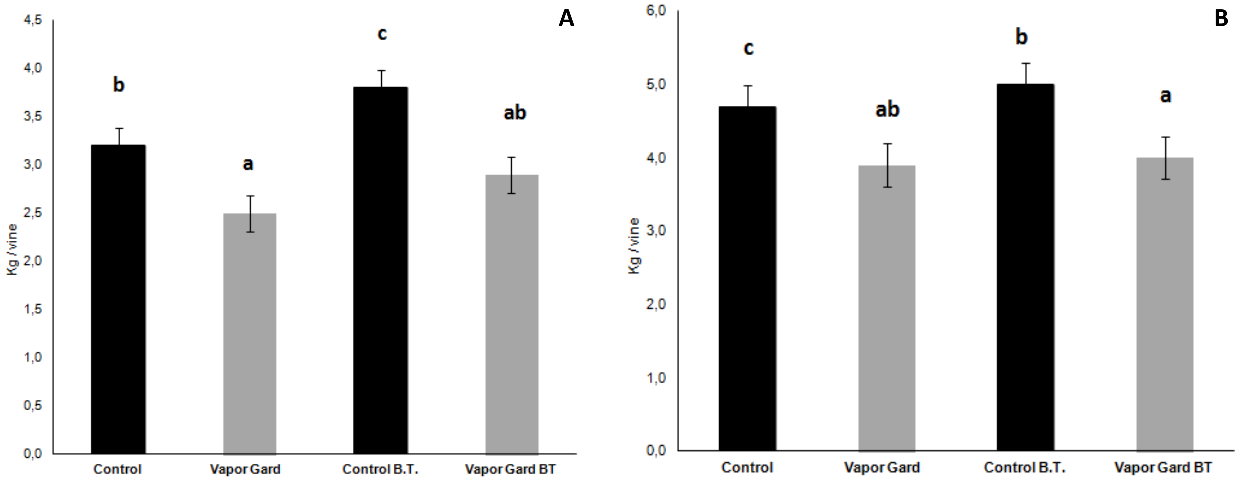

Figure 35 - Pruning weight/vine measured in Falanghina vines in 2013 (A) and 2014 (B). Data are mean ± SE. Same letter indicates not significant differences at Duncan post hoc test (p<0.05).

3.3 Conclusion 1

The application of the organic film-forming antitranspirant, Vapor Gard, on Aglianico and Falanghina vines post veraison and above the cluster zone is a suitable strategy to delay ripening in the berry as compared to nontreated vines. The method proved to be effective and easy to apply in order to hinder the sugaring of berries and to obtain wines with lower alcohol percentage. Concurrently this method had no other negative impact on phenolic compounds, organic acids, or pH in grape and wines. Moreover, the antitraspirant does not show adverse effects on the production per plant and berry size for each cultivar Aglianico and Falanghina and for each years 2013 and 2014. Application of anti-transpirant leads to a reduction in stomatal conductance and photosynthetic assimilation rate in Mediterranean climatic conditions. An increase in WUEi was also observed in Aglianico and Falanghina cultivars, with a consequent improvement of water use efficiency of vines. To be effective in reducing the accumulation of total soluble solids in the berries, the Vapor Gard emulsion should be applied at time of veraison and should completely wet the lower leaf surface where stomata are located. The effectivity of product depends also from the concentration of preparation, in our case the concentration of 2% has been shown very efficient. Another important aspect to consider is that after applying the antitraspirant product does not show any differences in the notes and in the wines characteristics produced in both years of trial.

After the sensory analysis and wine tasting no negative notes and nor unpleasant characteristics were detected in the wines produced. The reduction of the sugar content in the berries and the reduction of the alcohol content in the wines did not report any negative qualitative or quantitative characteristics that could affect the final product.

3.4 References 1

Baggiolini, M. (1952). Les stades repères dans le développement de la vigne et leur utilisation pratique, Station Féd. *Essais Agric., Lausanne*.

Brossaud, F., Cheynier, V., Asselin, C., & Moutounet, M. (1999). Flavonoid compositional differences of grapes among site test plantings of Cabernet franc. *American journal of enology and viticulture*, *50*(3), 277-284.

Carnevali, P., Falcetti, M. (2012). Utilizzo di antitraspiranti a base di pinolene per la modulazione della maturità glucidica. IV Convegno Nazionale di Viticoltura. CONAVI.TO. Asti. 10-11-12 July 2012.

Chaerle, L., Van Caeneghem, W., Messens, E., Lambers, H., Van Montagu, M., & Van Der Straeten, D. (1999). Presymptomatic visualization of plant–virus interactions by thermography. *Nature biotechnology*, *17*(8), 813-816.

Cohen, Y., Alchanatis, V., Meron, M., Saranga, Y., & Tsipris, J. (2005). Estimation of leaf water potential by thermal imagery and spatial analysis.*Journal of experimental botany*, *56*(417), 1843-1852.

Davenport, D. C., Fisher, M. A., & Hagan, R. M. (1972). Some counteractive effects of antitranspirants. *Plant physiology*, *49*(5), 722-724.

Fischer, U., & Noble, A. C. (1994). The effect of ethanol, catechin concentration, and pH on sourness and bitterness of wine. *American Journal of Enology and Viticulture*, *45*(1), 6-10.

Francini, A., Lorenzini, G., & Nali, C. (2011). The antitranspirant di-1-p-menthene, a potential chemical protectant of ozone damage to plants. *Water, Air, & Soil Pollution*, *219*(1-4), 459-472.

Glories, Y. (1978). *Recherches sur la matière colorante des vins rouges*. Université de Bordeaux II.

Goldberg, D. M., Karumanchiri, A., Tsang, E., & Soleas, G. J. (1998). Catechin and epicatechin concentrations of red wines: regional and cultivar-related differences. *American Journal of Enology and Viticulture*, *49*(1), 23-34.

Iriti, M., Picchi, V., Rossoni, M., Gomarasca, S., Ludwig, N., Gargano, M., & Faoro, F. (2009). Chitosan antitranspirant activity is due to abscisic acid-dependent stomatal closure. *Environmental and experimental botany*, *66*(3), 493-500.

Jones, H. G. (1999). Use of infrared thermometry for estimation of stomatal conductance as a possible aid to irrigation scheduling. *Agricultural and Forest Meteorology*, *95*(3), 139-149.

Lazzini, F., Mattii, G., Binda, C. (2012). Effetto di antitraspiranti sulla maturazione di uve Merlot. IV Convegno Nazionale di Viticoltura. CONAVI.TO. Asti. 10-11-12 July 2012.

Lindenthal, M., Steiner, U., Dehne, H. W., & Oerke, E. C. (2005). Effect of downy mildew development on transpiration of cucumber leaves visualized by digital infrared thermography. *Phytopathology*, *95*(3), 233-240.

Moftah, A. E., & Al-Humaid, A. R. I. (2005). Effects of antitranspirants on water relations and photosynthetic rate of cultivated tropical plant(Polianthes tuberosa L.). *Polish Journal of Ecology*, *53*(2), 165-175.

Palliotti, A., Panara, F., Famiani, F., Sabbatini, P., Howell, G. S., Silvestroni, O., & Poni, S. (2013). Postveraison application of antitranspirant di-1-p-menthene to control sugar accumulation in Sangiovese grapevines. *American journal of enology and viticulture*, *64*(3), 378-385.

Palliotti, A., PONI, S., Berrios, J. G., & BERNIZZONI, F. (2010). Vine performance and grape composition as affected by early-season source limitation induced with anti-transpirants in two red Vitis vinifera L. cultivars.*Australian Journal of Grape and Wine Research*, *16*(3), 426-433.

Palliotti, A., Poni, S., Petoumenou, D., Vignaroli, S. (2008). Limitazione modulata della capacità fotoassimilativa delle foglie mediante antitraspiranti ed effetti su quantità e composizione dell'uva. Atti "II Conv. Naz. Viticoltura", Marsala 14- 19 luglio. Italus Hortus 17 (suppl.3): 21-26.

Price, S. F., Breen, P. J., Valladao, M., & Watson, B. T. (1995). Cluster sun exposure and quercetin in Pinot noir grapes and wine. *American Journal of Enology and Viticulture*, *46*(2), 187-194.

Reynolds, A. G., Price, S. F., Wardle, D. A., & Watson, B. T. (1994). Fruit environment and crop level effects on Pinot noir. I. Vine performance and fruit composition in British Columbia. *American Journal of Enology and Viticulture,45*(4), 452-459.

Robinson, W. B., Weirs, L. D., Bertino, J. J., & Mattick, L. R. (1966). The relation of anthocyanin composition to color stability of New York State wines.*American Journal of Enology and Viticulture*, *17*(3), 178-184.

Rosati, A. (2007). Physiological effects of kaolin particle film technology: A review. *Funct. Plant Sci. Biotech.*, *1*, 100-105.

Shellie, K. C., & King, B. A. (2013). Kaolin-based foliar reflectant and water deficit influence Malbec leaf and berry temperature, pigments, and photosynthesis. *American Journal of Enology and Viticulture*, ajev-2012.

Sims, C. A., & Bates, R. P. (1994). Effects of skin fermentation time on the phenols, anthocyanins, ellagic acid sediment, and sensory characteristics of a red Vitis rotundifolia wine. *American Journal of Enology and Viticulture*, *45*(1), 56-62.

Strasserf, R. J., & Srivastava, A. (1995). Polyphasic chlorophyll a fluorescence transient in plants and cyanobacteria*. *Photochemistry and photobiology*, *61*(1), 32-42.

Tittmann, S., Stöber, V., Bischoff-Schaefer, M., & Stoll, M. (2013). Application of anti-transpirant under greenhouse conditions of grapevines (*Vitis vinifera* cv. Riesling and cv. Müller-thurgau) reduce photosynthesis. 07/2013; DOI:ISSN 0254-0223 In the proceedings of the 18th International GiESCO. Porto. 7-11 July 2013. 8-12. Volume: 28

Wightman, J. D., Price, S. F., Watson, B. T., & Wrolstad, R. E. (1997). Some effects of processing enzymes on anthocyanins and phenolics in Pinot noir and Cabernet Sauvignon wines. *American Journal of Enology and Viticulture*, *48*(1), 39-48.

Yokotsuka, K., Nagao, A., Nakazawa, K., & Sato, M. (1999). Changes in anthocyanins in berry skins of Merlot and Cabernet Sauvignon grapes grown in two soils modified with limestone or oyster shell versus a native soil over two years. *American journal of enology and viticulture*, *50*(1), 1-12.

Zoecklein, B. W., Fugelsang, K. C., Gump, B. H., & Nury, F. S. (1995). *Wine analysis and production* (pp. 407-409). New York: Chapman & Hall.

4.0 TRIAL 2 (SOUTHERN AUSTRALIA)

Anti-transpirant effects on grape physiology and berry and wine composition of Shiraz and Semillon (*Vitis vinifera* L.) grown in Southern Australia

Summary

Plant growth, yield and quality are highly dependent on climate. In the last few decades the trend of increasing global temperatures has affected the accumulation of sugars in grape berries and hence the degree of alcohol in resultant wines. Therefore numerous studies have considered different agronomic practices to limit photosynthetic activity in order to, reduce sugar accumulation in berries. Our study was designed to determine whether similar results could be reproduced by using a film-forming anti-transpirant. In 2014, in South Australia, Shiraz and Semillon vines were sprayed at early veraison and full veraison respectively with the anti-transpirant Vapor Gard® (T) and compared with a control (C) sprayed with only water. A bunch thinning (BT) treatment was also applied to both the Vapor Gard® treatment and the control. The results demonstrate that the application of anti-transpirant reduces photosynthetic activity, accumulation of sugars in the berries and hence wine alcohol content. No significant differences between treatments were observed for other wine compositional measures taken. Changes in berry compositional measures were not consistent between cultivars. It was also found that the time of application is critical to the effectiveness of the product.

4.1 Materials and Methods 2

4.1.1 Experimental site, design and treatments

The trial was carried out in the Coombe vineyard located at the Waite Research Precinct, The University of Adelaide, (34°9’ S. 138°6’ E.) in the 2013-14 growing season on two grapevine (*Vitis vinifera* L.) varieties: own-rooted Semillon (clone SA 32) and Shiraz grafted onto Ramsey rootstock. Vines were planted in 1991 with 3 m spacing between rows and 2.7 m between Shiraz vines and 1.8 m between Semillon vines. The vines were trained to a bilateral cordon with vertical shoot positioning (VSP) and hand-pruned to approximately 30–40 nodes per vine. All treatments were drip-irrigated and received irrigation during the growing season with scheduling based on soil moisture measurements. Daily air temperature (°C) and rainfall (mm) data was recorded from January 1st to March 31st 2014 and it was taken from a weather station (MEA-Measurement Engineering Australia Pty Ltd, Magill, SA, Asutralia) located 100 m from the vineyard site. A randomised block design including three replicated blocks of each treatment was used for both culivars. Four treatments were applied: a spray application of the anti-transpirant Vapor Gard® (VG) (T = treated vines) and a water spray application (C = control vines). Three days before the VG application, to each treatments a plus and minus bunch thinning (BT) treatment was applied at E-L stage X , with BT in Shiraz amounting to 50% of all bunches, and 30% of all bunches in Semillon. In total, 12 vines per treatment were assessed for Shiraz and 12 for Semillon.

VG was prepared as a 2% solution in water and stirred slowly to form an emulsion before treatment. The entire canopy of all T vines was sprayed with VG until run-off. The VG treatments were applied on Jan 19th 2014 for both cultivars. This date corresponded to different phenological stages for the two varieties: early veraison (E-L stage 35) for Shiraz and full veraison (E-L stage 37) for Semillon (Coombe 1995). Shiraz was harvested 53 days after spraying, Semillon after 25 days.

4.1.2 Physiological measurements

Stem water potential (Ψ_{stem}) was measured on each plant using a Scholander pressure chamber (PMS Instruments, Model 1005, Albany, OR. USA) (Scholander et al., 1965). For this purpose, a fully expanded mature leaf was selected from each plant and placed for at least 30 min before each measurement in a plastic bag coated with aluminium foil (n = 12). No more than 30 s elapsed between leaf cutting and measurement of the bagged leaves.

Assimilation rate (A), transpiration rate (E) and stomatal conductance (gs) were measured using a LCpro-SD Portable Photosynthesis System (ADC BioScientific Ltd., UK). Intrinsic water use efficiency (WUEi) was then derived as the A to gs ratio as described by Palliotti et al. (2010). All measurements were obtained from three mature and fully expanded leaves from each plant per replicate per treatment (36 leaves per treatment). All physiological measurements were performed on the same plants at midday (between 12:00 and 14:00 h).

4.1.3 Growth, yield and grape composition

Fifty berries per replicates were randomly collected each week for eight weeks prior to the 'after harvest' sampling point to obtain grape maturity data and to determine the harvest date for each variety. The berries were collected from random bunches and from different sections of the bunch – top, middle and bottom – and from exposed and non-sun exposed bunch sides to avoid bias. The 50 berries were weighted to determine berry weight and then crushed, juice was centrifuged and total soluble solids (TSS) (°Brix) were measured with a digital refractometer (Atago Pocket, Atago Co., Ltd. Tokyo. Japan). pH and titratable acidity (TA) (expressed as g/L of tartaric acid) were measured with a combined pH meter and autotitrator (Crison, CompacT Titrator, Crison Instruments, S.A., Allela, Spain) as described by Iland et al. (2004).

The experimental vines were individually picked, and yield and bunch number per vine were determined. At each harvest date 5 kg of fruit per replicate were randomly harvested and transported to the laboratory. The randomly picked bunches were collected from both sides of the vines and from shaded and non-shaded vine sections to avoid bias. Another 50 berries were collected, frozen and stored at −20 °C. After four weeks the frozen samples were defrosted overnight at 4 °C prior to anthocyanin and tannin analysis.

Five kg of fruit from each treatment and replicate were manually destemmed and crushed and the resulting juice used for microvinification. A solution of 15 grams of yeast (Maurivin® AWRI 796, Mauri Yeast Australia, Sydney, Australia) per 100 litres of must was added to the microferment after rehydration in water at a temperature of 38-40 °C. Diammonium phosphate (0.5 g/L) was added at the time of yeast inoculation when the ferments were between 18-20 ^{o}C. All fermentations were maintained at 18 °C ± 2 °C. The cap of red ferments was manually plunged every 12 hours for a period of 6 days or until fermentations reached 2˚ Baume (plunged approximately 18 times) after which all free run wine was collected through a sieve. Temperature and sugar content of the fermenting must were measured daily. At the end of fermentation, pH, titratable acidity and alcohol % were measured with a combined pH meter, autotitrator (Crison, CompacT Titrator, Crison Instruments, S.A., Allela, Spain) and ebulliometer as described by Iland et al. (2004). In the final wine, the content of anthocyanins was determined with the method described by Mercurio et al. (2007) and tannins following the procedure described by Sarneckis et al. (2006).

4.1.4 Statistical analysis

The data analysis package Genstat (10th Edition. 10.1.0.72. Lawes Agricultural Trust. 2007) was used to analyse berry compositional data. A two-way analysis of variance (ANOVA) was used to determine the effects of treatment of Vapor Gard and bunch thinning on all parameters observed. The F probability value (p) was used to determine statistically significant differences. The significantly different means of each treatment were determined by using a least significant difference (LSD) test at the 5% level for multiple comparisons.

4.2 Result and Discussion 2

The average monthly temperature recorded was 24.1 °C, 22.9 °C and 19.9 °C in January, February and March respectively. Peak temperatures over 34 °C were recorded in mid January, and at the beginning and middle of February. Total rainfall from January to March was 4.76 mm: 0.438 mm in January, 3.478 mm in February and 0.845 mm in March, the main rainfall event occurring on 14 February 2014 with 75 mm (Fig. 36).

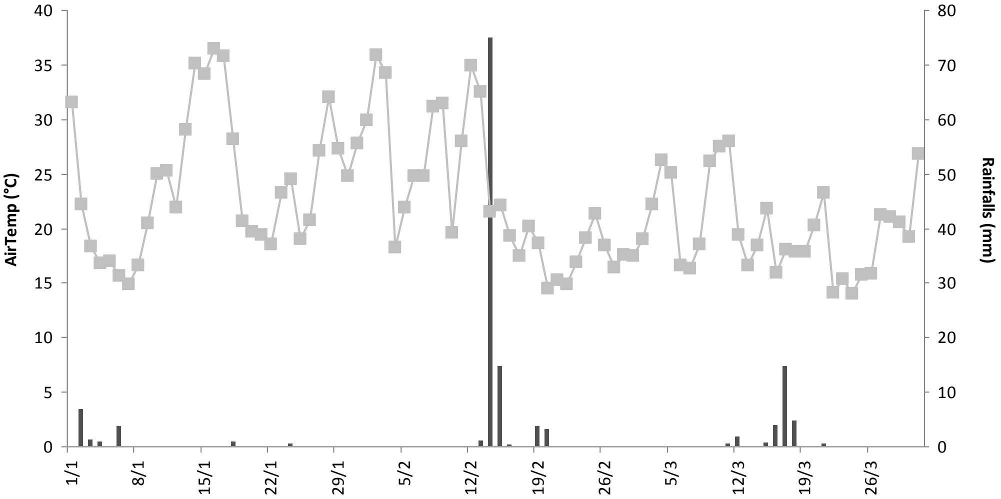

Figure 36 - Daily mean air temperature (°C) and rainfalls (mm) recorded from 1 January to 31 March 2014. The line indicate the seasonal temperature (°C) and the bars the rain.

Numerous authors reported general guidelines for vineyard water management based on Ψ_{stem} as follow: above -1.0 MPa (non-stress), between -1.0 to -1.2 MPa (moderate water restriction) and from -1.2 to -1.5 MPa (severe water restrictions) (Sibille et al. 2007; Ferreyra et al. 2003; Williams and Araujo, 2002; Cifre et. al 2005). According to these values, we can infer that during most of the period of observation the plants in our trial were not water stressed (Figure 37). Average Ψ_{stem} was – 0.99 to – 1.01 MPa for both Shiraz and Semillon, typical values of non-stressed plants reported elsewhere (Schultz 1995, Patakas et al. 2005). At the beginning of February, corresponding to very high temperatures, Ψ_{stem} was - 1.2 MPa for both cultivars, unique moment of stress in plants. No significant differences in water potential were recorded between treatments.

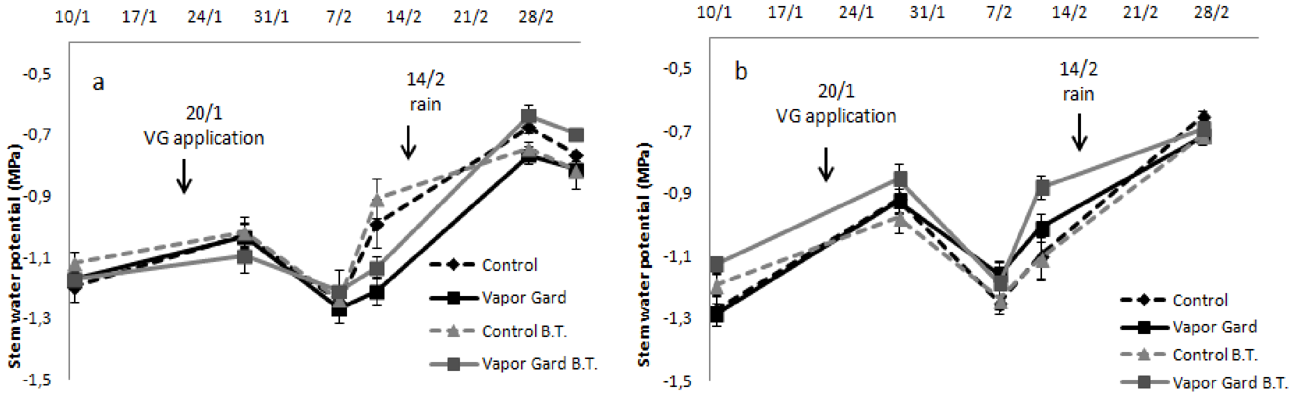

Figure 37 - Midday stem water potential (ψ_{stem}) measured during January and February 2014 on Shiraz (a) and Semillon (b) vines. Data are mean ± SE.

VG sprayed on Shiraz canopy at early veraison caused a 29% reduction in the leaf transpiration rate after one week from application and 13% on Semillon. This value was different for the treatment with bunch thinning (Fig. 38A). Transpiration one day after VG application was 3.945 mmol H_2O/m^2s in the control compared with the VG treatment value of 3.057 mmol H_2O/m^2s. The bunch thinning treatment also shows major differences in the transpiration rate: the control with BT was 4.093 mmol H_2O/m^2 and the sprayed treatment 3.222 mmol H_2O/m^2s. Prior to harvest (13/02 for Semillon and 06/03 for Shiraz) for Shiraz the minimum transpiration rate was 2.701 mmol H_2O/m^2s for VG-treated vines; with a similar result for Semillon (3.230 mmol H_2O/m^2s). In terms of stomatal conductance, the minimum was recorded in the VG treatment (0.198 mmol/m^2/s for Shiraz (Fig. 39A) and 0.270 (Fig. 39B) for Semillon one week after treatment. The photosynthesis rate also shows a reduction of 29% after one week for Shiraz and about 12% in Semillon (Fig.40 A-B) for treated vines. One month after application the results show a final transpiration reduction of 16 % for Shiraz and 15 % for Semillon, and 7.4% and 10% in terms of photosynthesis in Shiraz and Semillon, respectively, for VG-treated vines. These findings are comparable with those in the literature (Palliotti et al. 2010 and Tittmann et al. 2013). The decrease in transpiration is caused by the increase in resistance to the water transport related to the film-forming antitranspirant (Palliotti et al. 2010). For both varieties a stronger effect on transpiration than on photosynthesis was found. In agreement with the findings of Palliotti et al. (2010 and 2013) and Tittmann et al. (2013) in their greenhouse experiments, our study showed that two weeks after application Shiraz plants were able to recover, although a reduced photosynthesis rate compared to the control was still observed. As shown in the other study (Palliotti et al. 2010 and Tittmann et al. 2013), one week after treatment in the VG-sprayed Sangiovese leaves a large reduction in leaf assimilation (A) and transpiration (E) rates. In post-veraison the effect on stomatal closure was reduced in part, although transpiration rates were lower than the control even late in the season in agreement with Palliotti et al. (2010). The depression of E after VG application resulted in a significant increase in WUE in VG-treated relative to C vines (Figure 41). Our results are confirmed by other studies: Sangiovese and Ciliegiolo leaves showed a smaller decrease in WUE during the season in response to application of VG (Palliotti et al. 2010 and 2013). Semillon also showed a significant reduction in WUE for the VG treatment in particular two weeks after treatment (Fig. 41B).

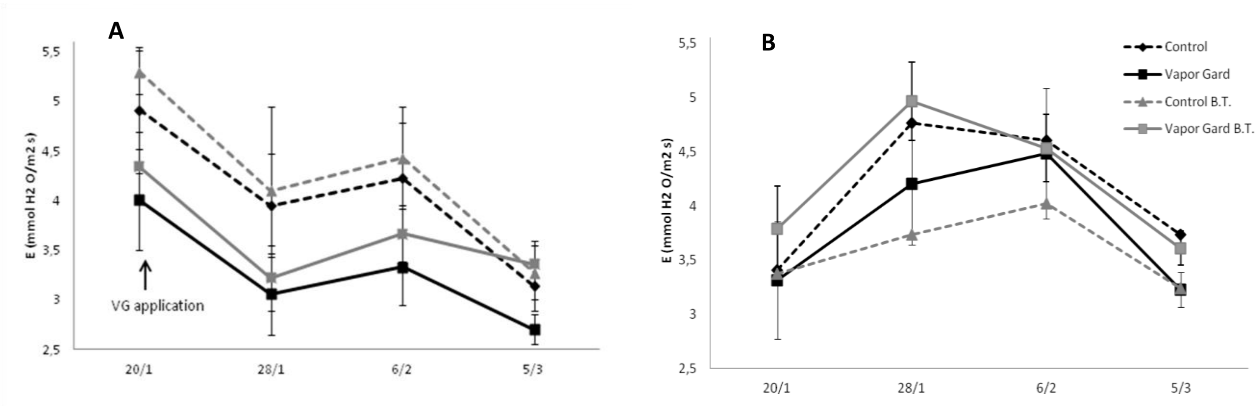

Figure 38 - Transpiration rate (E) measured in Shiraz (A) and Semillon (B) on fully expanded leaves sprayed with antitranspirant Vapor Gard® (VG) at 2% or left unsprayed (Control) with or without bunch thinning (BT). Data are mean ± SE.

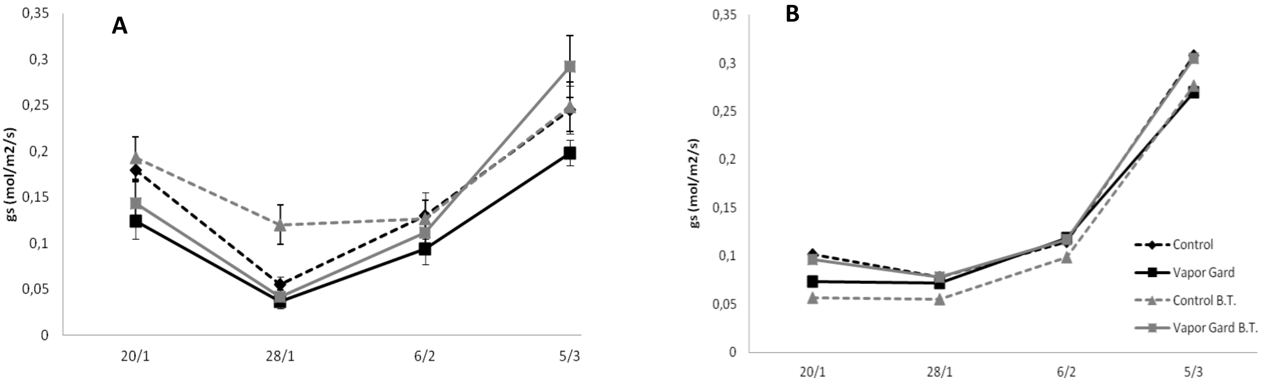

Figure 39 - Stomatal conductance (gs) measured in Shiraz (A) and Semillon (B) on fully expanded leaves sprayed with antitranspirant Vapor Gard® (VG) at 2% or left unsprayed (Control) with or without bunch thinning (BT). Data are mean ± SE.

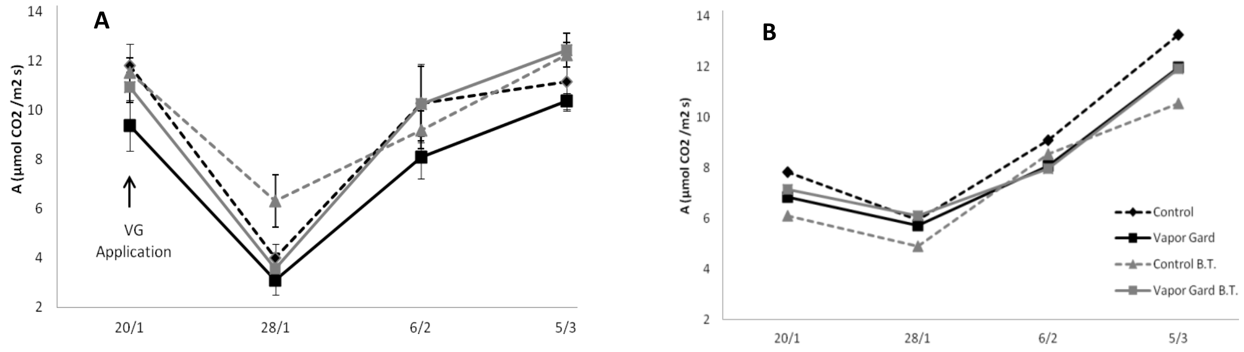

Figure 40 - Assimilation rate (A) measured in Shiraz (A) and Semillon (B) on fully expanded leaves sprayed with antitranspirant Vapor Gard® (VG) at 2% or left unsprayed (Control) with or without bunch thinning (BT). Data are mean ± SE.

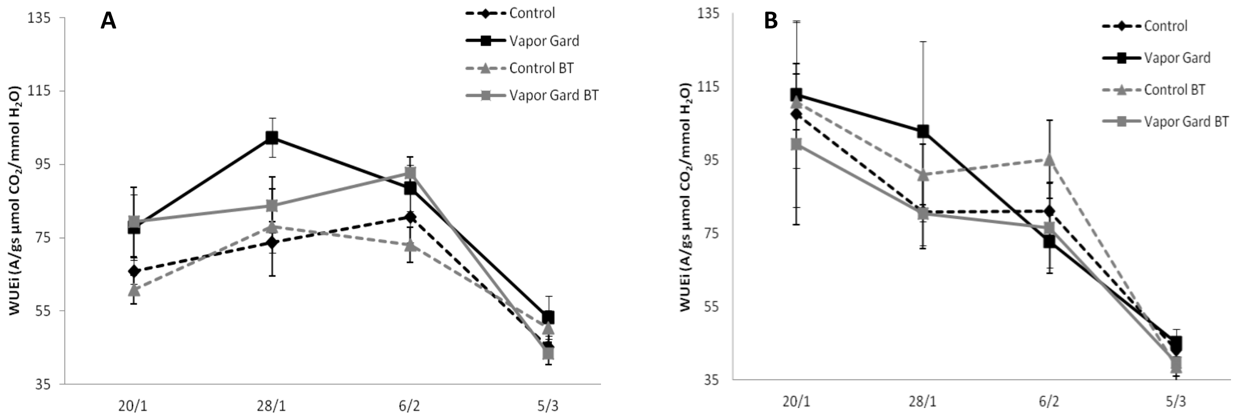

Figure 41 - Intrinsic water use efficiency (WUEi) calculated as A/gs measured in Shiraz (A) and Semillon (B) on fully expanded leaves sprayed with antitranspirant Vapor Gard® (VG) at 2% or left unsprayed (Control) with or without bunch thinning (BT). Data are mean ± SE.

From veraison to harvest we monitored average berry weight, soluble solids (°Brix), pH and total acidity for Shiraz and Semillon. As reported in Figure 4, it is possible to see how these parameters evolve during the season and to appreciate the significant differences both in berry weight and the content of soluble solids between treatments. Berry weight is lower for fruit from VG treated vines in the first 20 days after application (Fig. 42). Semillon berry weight is reduced, due to high temperatures, but the reduction also affects other treatments and the differences are not significant (Fig. 42b). Before harvest, all the weights are equal for both Semillon and Shiraz. Sugar accumulation in the berry showed that, regardless of treatment, the accumulation is slower about 15 days after VG treatment in accordance with other authors (Palliotti et al. 2010) (Figure 42 c-d). The reduction in total soluble solids found in VG-treated vines appears to be linked to impaired canopy photosynthetic capacity and/or limitation in sugar translocation from leaves to berries, according to other work of Palliotti et al. (2008). Between VG application and harvest, the rate of Brix accumulation in the berries decreased (Figure 42 c-d). Shiraz and Semillon TA and pH were unaffected during maturation (Fig.42 e- h) independently from treatment.

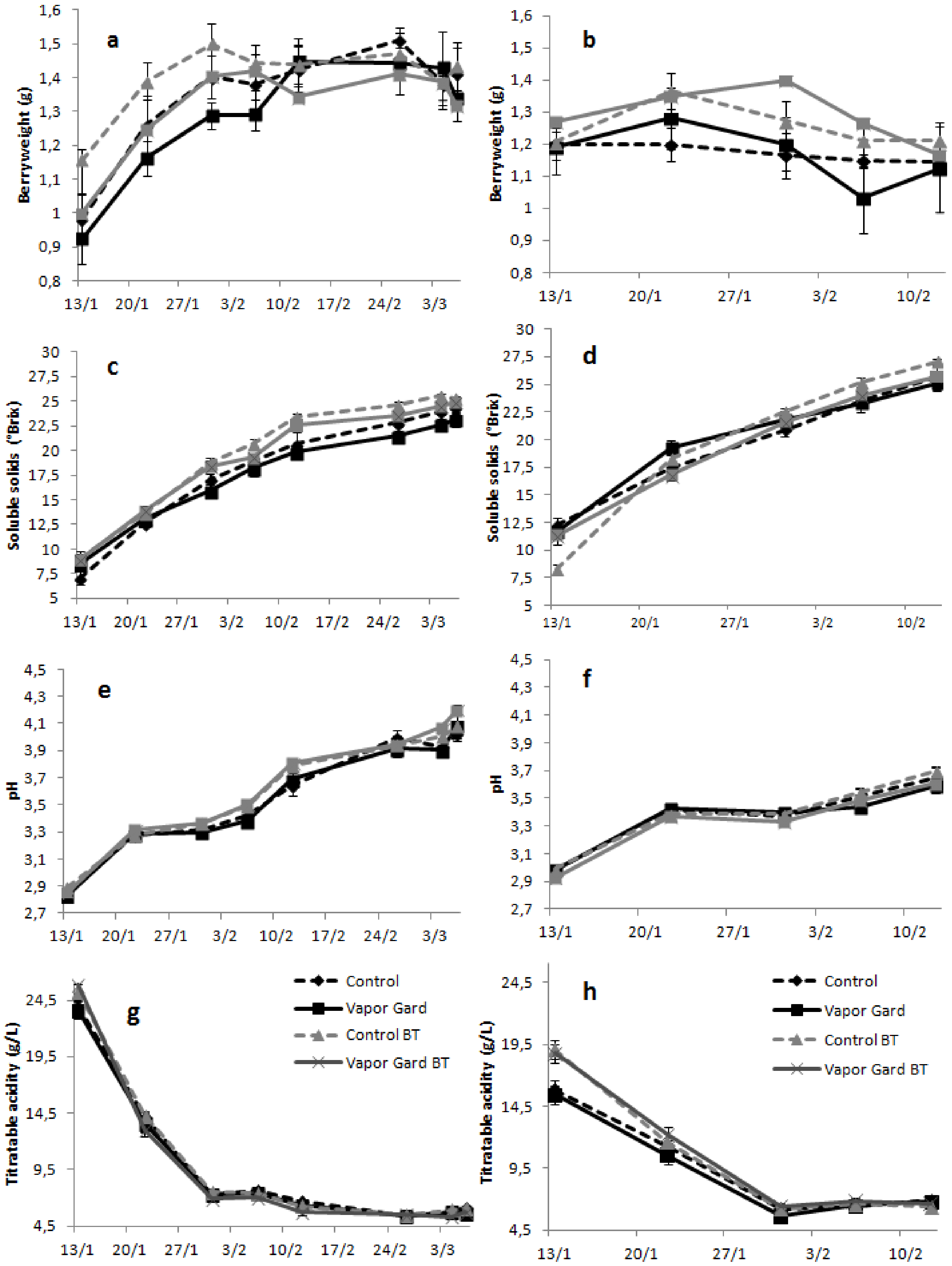
a
Berryweight (g)
1,6
1,5
1,4
1,3
1,2
1,1
1
0,9
0,8
13/1
20/1
27/1
3/2
10/2
17/2
24/2
3/3
b
Berryweight (g)
13/1
20/1
27/1
3/2
10/2
c
Soluble solids (°Brix)
30
27,5
25
22,5
20
17,5
15
12,5
10
7,5
5
d
Soluble solids (°Brix)
e
pH
4,5
4,3
4,1
3,9
3,7
3,5
3,3
3,1
2,9
2,7
f
pH
g
Titratable acidity (g/L)
24,5
19,5
14,5
9,5
4,5
h
Titratable acidity (g/L)
Control
Vapor Gard
Control BT
Vapor Gard BT

Figure 42 - Grape composition: berry weight (a-b), total soluble solids content (c-d), pH (e-f) and TA (g/L of tartaric acid) (g-h) determined in Shiraz and Semillon vines. Data are mean ± SE.

At harvest for Shiraz, we observed some differences in terms of yield/vine or bunches/vine between different canopy management (bunch thinning). The vines without bunch thinning had higher yields per vine than those with bunch thinning (12.6 *vs* 6.7 kg) Vapor Gard treatment and (13.4 *vs* 7.1 kg) Control. Different yield and yield components were not observed between VG-treated and control vines.

Regardless of treatment, VG applied at veraison above the bunch zone did not affect yield per vine or average cluster and berry weight (Table 6) in accordance with Palliotti *et al.* (2013). Similarly, no statistical differences was found in average bunch weight, average berry weight, juice pH, berry total phenolics (au) and total anthocyanins (mg/L) between treatments. Some statistical differences between treatment we can observed for berry epicatechin (mg/L), berry juice TA (expressed as g/L of tartaric acid) and °Brix berry. Analysis of the Shiraz wine shows some statistical differences in terms of pH and alcohol content (%). According to other authors (Palliotti et al. 2012; Carnevali and Falcetti 2012; Lazzini et al. 2012; Tittmann et al. 2013) we can observed significantly reduced (°Brix for berry and alcohol for wine) for treatment with regular canopy management and with bunch thinning, compared to C vines and VG vines (1.2 °Brix and 0.5 °Brix respectively). Bunch thinned treatments showed always higher sugar berries accumulation and alcohol content in the wine compared with un-thinned treatments (25.0 *vs* 23.7 bunch thinned and un-thinned respectively). At the same time Vapor Gard treatment shows to contain even sugar berries accumulation also in the case of lower number of bunches.

Wine alcohol content (%) was significantly reduced with VG and bunch thinning treatments, compared to C treatment and VG treatment (0.3 % and 0.6 % alcohol respectively) (Table 6).

Table 6 - Yield components, bunch morphology and grape composition recorded in Shiraz vines treated (VG) or not (Control) with or without bunch thinning (BT). For each parameter, values with the same letter are not significantly different by Duncan's post hoc test (P <0.05).

Parameters	Treatments				
	Control	Vapor Gard	Control BT *	Vapor Gard BT	Significance
Yield/vine (Kg)	13.4 a	12.6 a	7.1 b	6.7 b	0.046
Bunches/vine	79 b	76 b	40 a	40 a	0.035
Average bunch weight (g)	171	165	179	165	ns
Average berry weight (g)	1.41	1.34	1.43	1.32	ns
°Brix berry	24.3 b	23.1 a	25.3 b	24.8 b	0.05
Juice pH	4.02	4.08	4.08	4.20	ns
Juice TA (g/L of tartaric acid)	6.1 b	5.7 a	6.1 b	5.7 a	0.033
Berry epicatechin (mg/L)	592 b	413 a	667 b	897 c	0.047
Berry total phenolics (MCP) (au)	36.9	36.8	40.3	43.5	ns
Wine					
pH	3.97 b	3.90 a	4.05 b	3.97 b	0.045
TA (g/L of tartaric acid)	10.6	10.4	9.7	11.0	ns
Alcohol (%)	13.1 b	12.7 a	14.0 c	13.4 b	0.046
Total anthocyanins (mg/L)	503	459	555	551	ns
Colour density (au)	10.35	8.67	10.83	10.61	ns
Colour density: SO_2-corrected (au)	11.15	10.2	12.44	12.86	ns
Hue (no units)	0.60	0.59	0.60	0.58	ns
Total phenolics (au)	35.6	34.0	42.0	40.5	ns
SO_2-resistant pigments (au)	1.63	1.71	2.75	1.92	ns

* BT = 50% Bunch thinning at veraison

A different finding was demonstrated for Semillon. In this case, as the treatment was applied full-veraison, harvest took place 25 days after treatment, for this reason the effect of the plastic film was less effective. As shown in Table 7, there were significant differences in epichatechin (mg/L) and total phenolics (MCP) in the berries and wine alcohol content (%) according to other studies (Palliotti et al. 2013). Wines made from Semillon grapes of VG-treated vines had a 0.87 % lower alcohol content than wines made from grapes of C vines, while average bunch weight, average berry weight, juice pH and TA, wine pH, TA and total phenolics were similar (Table 7). The epicatechin concentration (mg/L) significantly increased in BT and VG treated vines . Of interest is the value for total berry phenolics (MCP) for the treatment with bunch thinning. Elsewhere, differences between treatments were found to disappear when anthocyanins and phenolics were expressed on a per-berry basis (Palliotti et al. 2010). Semillon also for smallest number of bunches per plant favored a greater sugar berries accumulation (26.3 *vs* 25.4 °Brix bunch thinned and un-thinned treatment respectively), still controlled by the effect of the VG treatment (Table 7).

Table 7 - Yield components, bunch morphology and grape composition recorded in Semillon vines treated (VG) or not (Control) with or without bunch thinning (BT). For each parameter, values with the same letter are not significantly different by Duncan's post hoc test (P <0.05).

Parameters	Treatments				
	Control	Vapor Gard	Control BT	Vapor Gard BT	Significance
Yield /vine (Kg)	4.4	4.4	3.4	4.5	ns
Bunches /vine	35.8	37.6	26.0	31.3	ns
Average weight bunch (g)	122	119	128	143	ns
Average berry weight (g)	1.14	1.12	1.21	1.17	ns
°Brix berry	25.7	25.1	27.0	25.6	ns
Juice pH	3.65	3.59	3.70	3.61	ns
Juice TA (g/L of tartaric acid)	6.91	6.79	6.37	6.67	ns
Berry epicatechin (mg/L)	319 a	409 ab	481 b	428 b	0.045
Berry total phenolics (MCP)	5.8 a	6.9 ab	7.9 b	7.0 ab	0.05
Wine					
pH	3.40	3.34	3.42	3.42	ns
TA (g/L of tartaric acid)	11.46	12.37	11.55	12.09	ns
Alcohol (%)	13.2 a	13 a	14.4 b	13.53 a	0.015
Hue (no units)	2.01	2.15	2.1	1.57	ns
Total phenolics (au)	7.35	2.97	3.36	3.48	ns
SO_2 resistant pigments (au)	0.11	0.09	0.1	0.12	ns

* BT = 30% Bunch thinning at veraison

4.3 Conclusions 2

Application of anti-transpirant leads to a reduction in stomatal conductance and, to a lesser extent, in net photosynthesis under hot weather conditions. An increase in WUEi was also observed in Shiraz cultivar. This method is a useful tool to reduce berry sugar content which can result in lower alcohol content in wines. We can confirm that the time of application is critical to the effectiveness of the product; in the case of Semillon the treatment was performed in full veraison, by which time the sugars had in part already accumulated, thereby resulting in a lower reduction. We thus confirm findings elsewhere the most suitable time of treatment for maximum effectiveness for reducing sugars at veraison, approximately one month before harvest in hot regions. Vapor Gard shows un effective containing of sugar accumulation also with a smaller bunches number. Concurrently this method had no other negative impact on phenolic compounds, organic acids, or pH in grape and wines. Moreover, the antitraspirant does not show adverse effects on the production per plant and berry size for each cultivars Shiraz and Semillon.

It is conceivable that a localised late season VP application (e.g. around veraison) might be envisaged as a tool to delay ripening in warm areas where under pressure of global warming sugar accumulation is too rapid, acidity too low and flavours are untypical (Jones et al. 2005). A result in agreement with prior studies using film-forming compounds on herbaceous crop species (Anderson and Kreith 1978, Ceulemans et al. 1983), on vine in field (Palliotti et al. 2010 and 2013) and under greenhouse conditions (Tittmann et al. 2013). Finally under field conditions the usage of film-forming AT can be an effective practice to modify sugar accumulation in the berries.

4.4 References 2

Anderson, J.E. and Kreith, F. (1978). Effects of film-forming and silicone anti-transpirants of four herbaceous plant species. *Plant and Soil* 49, 161–173.

Carnevali, P., Falcetti, M. (2012). Utilizzo di antitraspiranti a base di pinolene per la modulazione della maturità glucidica. IV Convegno Nazionale di Viticoltura. CONAVI.TO. Asti. 10-11-12 July 2012.

Ceulemans, R., Gabriels, R., & Impens, I. (1983). Antitranspirant effects on transpiration, net CO 2 exchange rate and water-use efficiency of azalea.*Scientia Horticulturae*, *19*(1), 125-131.

Coombe, B. G. (1995). Growth stages of the grapevine: adoption of a system for identifying grapevine growth stages. *Australian Journal of Grape and Wine Research, 1*(2), 104-110.

Cifre, J., Bota, J., Escalona, J. M., Medrano, H., & Flexas, J. (2005). Physiological tools for irrigation scheduling in grapevine (Vitis vinifera L.): An open gate to improve water-use efficiency?. *Agriculture, Ecosystems & Environment*, *106*(2), 159-170.

Ferreyra, E., Sellés, V., Ruiz, S., & Sellés, M. (2003). Efecto del estrés hídrico aplicado en distintos períodos de desarrollo de la Vid cv. Chardonnay en la producción y calidad del vino. *Agricultura Técnica*, *63*(3), 277-286.

Iland, P., Bruer, N., Edwards, G., Weeks, S., & Wilkes, E. Chemical Analysis of Grapes and Wine: Techniques and Concepts. Patrick Iland Wine Promotions; Campbelltown, Australia: 2004. *There is no corresponding record for this reference*, 32-58.

Lazzini, F., Mattii, G., Binda, C. (2012). Effetto di antitraspiranti sulla maturazione di uve Merlot. IV Convegno Nazionale di Viticoltura. CONAVI.TO. Asti. 10-11-12 July 2012.

Jones, G. V., White, M. A., Cooper, O. R., & Storchmann, K. (2005). Climate change and global wine quality. *Climatic change*, *73*(3), 319-343.

Mercurio, M. D., Dambergs, R. G., Herderich, M. J., & Smith, P. A. (2007). High throughput analysis of red wine and grape phenolics adaptation and validation of methyl cellulose precipitable tannin assay and modified somers color assay to a rapid 96 well plate format. *Journal of agricultural and food chemistry*, *55*(12), 4651-4657.

Palliotti, A., Panara, F., Famiani, F., Sabbatini, P., Howell, G. S., Silvestroni, O., & Poni, S. (2013). Postveraison application of antitranspirant di-1-p-menthene to control sugar accumulation in Sangiovese grapevines. *American journal of enology and viticulture*, *64*(3), 378-385.

Palliotti, A., PONI, S., Berrios, J. G., & BERNIZZONI, F. (2010). Vine performance and grape composition as affected by early-season source limitation induced with anti-transpirants in two red Vitis vinifera L. cultivars.*Australian Journal of Grape and Wine Research*, *16*(3), 426-433.

Palliotti, A., Poni, S., Petoumenou, D., Vignaroli, S. (2008). Limitazione modulata della capacità fotoassimilativa delle foglie mediante antitraspiranti ed effetti su quantità e composizione dell'uva. Atti "II Conv. Naz. Viticoltura", Marsala 14- 19 luglio. Italus Hortus 17 (suppl.3): 21-26.

Palliotti, A., Silvestroni, O., Lanari, V., Leoni, F., Cini, R., Poni, S. (2012). Controllo dell'accumulo degli zuccheri in vitigni a bacca bianca e nera mediante applicazione tardiva dell'antitraspirante Vapor Gard. IV Convegno Nazionale di Viticoltura. CONAVI.TO. Asti. 10-11-12 July 2012.

Patakas, A., Noitsakis, B., & Chouzouri, A. (2005). Optimization of irrigation water use in grapevines using the relationship between transpiration and plant water status. *Agriculture, ecosystems & environment*, *106*(2), 253-259.

Sarneckis, C. J., Dambergs, R. G., Jones, P., Mercurio, M., Herderich, M. J., & Smith, P. A. (2006). Quantification of condensed tannins by precipitation with methyl cellulose: development and validation of an optimised tool for grape and wine analysis. *Australian Journal of Grape and Wine Research*, *12*(1), 39-49.

Scholander, P. F., Bradstreet, E. D., Hemmingsen, E. A., & Hammel, H. T. (1965). Sap Pressure in Vascular Plants: Negative hydrostatic pressure can be measured in plants. *Science*, (148), 339-46.

Schultz, H. R. (1995). Water relations and photosynthetic responses of two grapevine cultivars of different geographical origin during water stress.*Strategies to Optimize Wine Grape Quality 427*, 251-266.

Sibille, I., Ojeda, H., Prieto, J., Maldonado, S., Lacapere, J. N., & Carbonneau, A. (2007). Relation between the values of three pressure chamber modalities (midday leaf, midday stem and predawn water potential) of 4 grapevine cultivars in drought situation of the southern of France. Applications for the irrigation control. In *Conference of Groupe d'Etude des Systèmes de Conduite de la Vigne (GESCO).*

Tittmann, S., Stöber, V., Bischoff-Schaefer, M., & Stoll, M. (2013). Application of anti-transpirant under greenhouse conditions of grapevines (*Vitis vinifera* cv. Riesling and cv. Müller-thurgau) reduce photosynthesis. 07/2013; DOI:ISSN 0254-0223 In the proceedings of the 18th International GiESCO. Porto. 7-11 July 2013. 8-12. Volume: 28

Williams, L. E., & Araujo, F. J. (2002). Correlations among predawn leaf, midday leaf, and midday stem water potential and their correlations with other measures of soil and plant water status in Vitis vinifera. *Journal of the American Society for Horticultural Science*, *127*(3), 448-454.

5. GENERAL CONCLUSIONS

The trend of planet climate change are now certainties consolidated and their impact on agriculture is increasingly evident. Viticulture certainly no exception to the new cultivation requirements that the climate imposes, especially in function of the extreme events frequency. A medium - long term strategy will certainly provide for an upgrade ampelography platform, especially for what concerns the availability of vines, new clones and new rootstocks resistant to abiotic stress, water scarcity and thermal excess and radiative in particular. At the same time, it will be necessary certainly increase knowledge, especially for vines of territory, on the mechanisms by which adapt to varying conditions of radiation, temperature, vapor pressure deficits and water availability. The challenge that awaits us in the near future, thrust also by new needs market, is to obtain products with a moderate alcohol content without, in red wines, change the intensity of color, texture and sensory properties and, in white wines, preserve the acidic and aromatic properties. A structural aid to do so could result from a careful review of the criteria for choosing the training system breeding in the design phase of the vineyard which take more account of scenarios, especially climate, that are emerging for the near and far future. Certainly, in the short term, the possibility of moderation by the effects induced by climate change, from one hand, and the new needs of the market, on the other, are related to adjustments of the technique cultivation be applied without revolutionize farming protocols consolidated and often rewarded by market success, but without opposing barriers to those which are applications often calibrated, though certainly not conventional, the same techniques. Finally, some techniques recently used such as the use of antitraspirants and / or defoliation later, that is applied when the berry process growth is practically complete, to our knowledge never experienced before, could make a real help to businesses wine that express the need to contain the sugars grapes accumulation of effectively as well as simple and economical.