PILOTING GRAPE RIPENING IN A GLOBAL WARMING SCENARIO: FEASIBLE TECHNIQUES ARE AVAILABLE

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Abstract:
Under the pressure of global warming, several wine grape growing regions around the world are increasingly suffering from advanced and compressed phenology; endangering wine character while also creating serious logistic problems. From a physiological standpoint, the issue of delaying ripening is not simple as, in several instances, only a few processes must be delayed (i.e. sugar accumulation into the berries) while other events such as pigmentation and accumulation of other important phenolic compounds should proceed at a normal rate. Thus, the issue of decoupling technological maturity from phenolic maturity is another important consideration. Over the last decades, several research groups have endeavored to establish alternate cultural practices aimed at addressing this decoupling. In some cases, special applications of quite robust and well known practices regarding physiological principles have been utilized, however some completely new techniques are also being studied. In figure 1 of the review, we offer a panorama of the available tools and in the text we elaborate on those having provided most reliable and consistent results under an array of genotypes and environmental conditions. Among these, primary focus is given to post-veraison—apical to the cluster—leaf removal (that can also be suitably replaced by applications of anti-transpirants); the use of kaolin against multiple summers' stresses; and a drastic version of late winter pruning having the potential to postpone ripening into a cooler period with improved grape composition and a limited negative impact on yield and storage reserves replenishment.
Keywords:

1. Introduction

Among the several data examples that can be provided to support the large effect of global warming on viticulture, one stands out for both importance and consistency: the increase in the average alcohol content of final wines. From 1971-2001, the change has been +2.3° in Napa Valley (Vierra, 2004), + 1.6° in red Australian wines from 1984 to 2004 (Webb et al. 2011), +2.5° in Riesling grown in Alsace (France) over a 30 year span (Duchene and Schneider, 2005). However, the overall impact of global warming—specifically more erratic seasonal rainfall, increased heat summation associated to enhanced evaporative demand, and higher frequency of hot spells—is much larger, causing, in warm areas, a vast number of problems. Among them, those deserving citation are: i) earlier and more compressed phenology leading, for instance, (as it happened in 2017 in several regions of France and Italy) to more exposure to frost damage: ii) faster organic acid depletion and increased must pH with related enological consequences; iii) variation in the degree of coupling between technological and phenolic ripeness with tendency for the former to be accelerated and the latter to be postponed and iv) higher incidence of multiple summer stresses (water deficit, light and heat stress) and subsequent berry dehydration and sunburn damage. In contrast with southern Europe, future warmer climates may be beneficial for many regions in central and western Europe where the warming will enable the growth of a wider range of varieties (Malheiro et al. 2010). As an example, Eitzinger et al. (2009) project a doubling of the potential winegrape-growing areas in Austria by the 2050s.
Despite this, in warmer growing regions, general belief is that warming is only partially responsible for phenology compression and early ripening. Indeed, other causes that might have helped diminish the time interval needed to reach full ripening are: i) improved vineyard design aimed at optimizing total light interception and light distribution inside the canopy; ii) optimized cultural practices; iii) better and

healthier propagation material; iv) law restrictions in yield threshold per surface basis and v) preference for low yielding cultivars or clones.

Data show that low-alcohol beverages, such as 'light' beer and reduced-alcohol wine, have become more acceptable in the marketplace and forecasts assume a continuous growth for low-alcohol beverages (Bucher et al, 2018). Although reasons for such a trend are multiple and vary by location, key factors often are: i) a particular tax break which makes the product much cheaper in comparison with standard wines; ii) consumers' increasing concerns about their health, or more draconian drink-drive laws, or simply their preference to stay clear-headed and in control.While previous studies have reported negative attitudes to low alcohol wine products, it is nowadays clear that these attitudes stem predominately from the alteration in taste, rather than from the reduction in alcohol per se. Undoubtedly many consumers will still prefer a higher alcohol wine, but the option of a similar tasting, lower alcohol wine to consume if driving or for health benefits and physical reasons is a market waiting to be conquered.

Within the above scenario, short-term adaption solutions are needed to counteract the effects of excessively compressed ripening, often leading to either unbalanced or atypical wines. While a general summary is shown in Figure 1, some of these, all focusing on vineyard related practices, will be presented and discussed in the following paragraphs.

2. Tools for grape ripening modulation

2.1. Let's not forget the simple solutions

If the need is to decompress ripening and extend it into what will likely be a cooler period, two quite obvious—yet often neglected—options are available before more complicated or uncertain solutions are sought. The first deals with the quite robust model linking grape "quality" with total leaf area to fruit ratio (LA/F) showing a plateau at 1-1.5 m^2/kg and then a steady phase before quality might worsen again due to excessive LA/F. Choice of simply imposing a higher yet calibrated crop load on the vines, hence reducing LA/F towards values that might start to be limiting is simple and achievable by adjusting winter pruning and/or reducing or eliminating shoot and/or cluster through thinning. The second possibility links to the well-known competitive relationships between vegetative and reproductive sinks (Keller, 2015). General rule is that complete ripening is favored by no overlap between active shoot growth and fruit maturation, taking veraison as its ideal starting point. Conversely, if the need is to slow the ripening pace, then some late season vegetative competition (e.g. by promoting lateral shoot development) towards the maturing clusters can be quite effective. Late season shoot trimming and/or irrigation are simple tools that can be used to achieve this goal.

2.2. Apical to the clusters late leaf removal

Based on well-established leaf age versus P_n relationships, which attribute highest functionality to leaves located in the median shoot zone for the period between fruit set and veraison and best P_n performance to apical leaves in the post-veraison period, Poni at al. (2013) conceived that ripening can be conveniently delayed through pre- or post veraison leaf removal, which, in contrast with the traditional approach, is deliberately performed in the upper two-thirds of the canopy (i.e. apical to the bunches), where the most functional leaves are located at that time of the season (Figure 2).

To verify the hypothesis, potted cv. Sangiovese grapevines were subjected to leaf removal treatments applied pre-veraison (DEF-I) and post-veraison (DEF-II) by pulling out six to seven primary leaves and laterals, if any, above the bunch zone; untouched vines served as the control. Whole-canopy net CO_2 gas exchange was monitored seasonally from 9 days before DEF-I to 35 days after DEF-II. The seasonal carbon/yield ratio did not differ between treatments because of the high capacity for photosynthetic compensation shown by the DEF treatments and quantified as about a 35% higher net CO_2 gas exchange per unit of leaf area per day. While ripening was temporarily retarded in both DEF treatments, with sugar content being lower and titratable acidity higher, a week later both treatments had fully or partially recovered; phenolic ripening was unaffectedat either harvest date. Main conclusion was that defoliation above the bunch zone applied at lag-phase and post-veraison (average 12-14 °Brix) was effective in temporarily delaying technological ripeness without affecting color and phenolics.

To verify effectiveness of the technique in the field, in 2011 and 2012, defoliation treatments were applied post-veraison to cv. Sangiovese vines (D) on either side of each row using a mechanical leaf remover, and these D vines were compared to a non-defoliated control (C) (Palliotti et al. 2013). The machine removed 35% of the leaves on the vine and created a 50-cm vertical window without leaves above the bunch area, but retained a few leaves at the canopy apex (about 0.50 m^2/vine). In both years, leaf removal reduced the rate of berry sugar accumulation and led to fruit with 1.2 °Brix lower at harvest and consequently, a lower wine alcohol (−0.6%) content in D relative to that of C vines. In 2012, sugar content of D vines, monitored in a group of vines that was not harvested, had recovered to that of C vines 2 weeks after harvest. The concentration of total phenolic compounds in the grapes, the chemical and chromatic characteristics of the wines and the replenishment of soluble sugars, starch and total nitrogen in the canes and roots were similar in the D and C vines. In conclusion, to achieve an effective delay in sugar accumulation in the berries, leaves should be removed at 14-16 °Brix, and at least 30–35% of vine leaf area should be pulled. More recent work on the technique involving white cultivars (Gatti et al. 2019) has shown that, due to shorter time span elapsing between veraison and ripening, some genotypes are more reluctant to respond and modifications should be considered (i.e. a pre-veraison treatment or an increase of the severity of defoliation).Interestingly, the operation can be mechanized at higher speed than any basal leaf removal since the working area is bunch-free and does not directly impact on bunch microclimate, which remains unchanged as compared to non-defoliated vines.

2.3. Anti-transpirants

Similarly to what it was achieved with the early leaf removal and to provide growers with an additional, non-invasive technique, the effectiveness of a post-veraison application of the film-forming anti-transpirant Vapor Gard (VG, a.i. di-1-*p*-menthene) was investigated as a technique to delay grape ripening and reduce sugar accumulation in the berry (Palliotti et al. 2013). The study was carried out over the 2010–2011 seasons in a non-irrigated vineyard of cv. Sangiovese in central Italy. VG was applied at 2% concentration to the upper two-thirds of the canopy (most functional leaves) and it significantly lowered leaf assimilation and transpiration rates and increased intrinsic water use efficiency. In both years, VG treatment reduced the rate of sugar accumulation in the berry as compared to control vines, scoring a -1.2 °Brix at harvest and wine alcohol content at −1% without compromising the recovery of concentrations of carbohydrates and total nitrogen in canes and roots. Concurrently, organic acid, pH, and phenolic concentrations of grapes and wines were unaffected. The application of VG at post-veraison above the cluster zone is an effective, simple, and viable technique to hinder berry sugaring and obtain less alcoholic wines. To be effective, the spraying should be performed at 12-14 °Brix, making sure that the lower leaf epidermis is fully wetted by the chemical.

2.4. Kaolin

Among the short term options, the use of reflective particle material, such as kaolin, having the ability to reflect Infrared, PAR and ultraviolet radiation is not a new approach (Glenn and Puterka, 2005). In fact, it is quite well known that, due to modifications in the leaf and fruit texture after spraying as well as changes in the reflected light signature of the plant, kaolin (KL) is able to exert a repellent action against a number of damaging insects afflicting different crops (D'Aquino et al. 2011). At the same time, kaolin demonstrated to be effective at reducing leaf and fruit sunburn damage in several fruit crop species including apple (Aly et al. 2010), pomegranate (Sharma et al, 2018), coffee (Da Silva et al. 2019) and grapevine (Dinis et al, 2018).

More recently, especially in olive and grapevine, work has been published investigating in greater details the defense mechanism promoted by kaolin applications against multiple summer stresses. Under the quite stressful conditions of the Douro region (Dinis et al., 2018), KL sprayed leaves displayed decreased susceptibility to photo-inhibition due to higher efficiency of the PSII system and a more efficient photochemical quenching. Transcriptional analyses and enzymatic activity essays carried out under similar harsh conditions (i.e. high temperature and irradiance) have shown that KL increases sucrose concentration in leaves and sucrose transport and phloem loading capacity (Conde et al., 2018).

Not too surprisingly, the cooling effect exerted on the fruit by the KL sprays has enhanced their quality, especially in terms of better and more uniform pigmentation. This effect has been repeatedly shown in apple (Glenn and Puterka 2005, Aly et al, 2010) and especially in the grapevine, in which a high number of red cultivars might greatly benefit from a lowered fruit surface temperature under high irradiance conditions (Poni et al. 2018). For instance, KL sprays increased the concentration of total monomeric anthocyanins over three consecutive seasons in the cv. Malbec grown under arid conditions with high solar radiation in Idaho (Shellie and King, 2013).

Due to its long lasting ability to change the reflective properties of the sprayed organ and the consequent cooling effects, kaolin is also expected to significantly affect leaf photosynthesis and water status and, consequently, water use efficiency. In grapevines, though, variability of kaolin's effect on leaf physiology is a bit confusing. Some papers have reported that single leaves sprayed with kaolin display a concurrent increase or invariance of A, gs, leaf water potential and intrinsic WUE (Attia et al., 2014; Brillante et al, 2016, Dinis et al, 2018), whereas other authors (Shellie and King, 2013) have shown a decrease in leaf assimilation rates due to kaolin sprays that was unrelated to the magnitude of leaf reflectance of visible light. A very recent paper (Frioni et al. 2019, in press) has tackled whole-canopy gas exchange readings of control (C) vs. KL sprayed vines under well-watered (WW) or water deficit (WS) conditions. Over a total period of 60 measuring days, mean NCER of WW-C was 6.7 µmol m^{-2} s^{-1} vs. versus 5.6 µmol m^{-2} s^{-1} for WW-KL (Figure 3). Within WS treatments, while mean NCER during stress was exactly the same for the two treatments (2.2 µmol m^{-2} s^{-1}), a clear trend was shown to have higher NCER in WS-KL over the last days of water deficit (Figure 3). Interestingly, NCER resumption upon re-watering was prompter in WS-KL and mean NCER calculated over the DOY219-232 time frame resulted in 6.4 µmol m^{-2} s^{-1} vs. 5.4 µmol m^{-2} s^{-1} ($P < 0.01$). In unsprayed vines, mean NCER reduction during stress was 67% compared to rates recorded on WW vines, whereas, upon rewatering, mean NCER of WS-C calculated over DOY 219-259 was still 22% less than WW plants. Same analysis carried out on KL sprayed vines showed that water stress curtailed NCER by 64 % whereas, upon re-watering, NCER of WS-KL calculated over DOY 219-259 was only 5% less than WW-KL.

2.5. Late winter pruning

If manipulating or shifting the annual grapevine growing cycle to offset limitations imposed by global warming is a must today, delayed winter pruning is indeed a tool to achieve it. However, limited information is available about its physiological background, especially in relation to modifications in canopy phenology, demography and seasonal carbon budget (Friend and Trought, 2007). Mechanistic hypothesis is that very late winter pruning can achieve significant postponement of phenology so that ripening might occur in a cooler period and, concurrently, ripening potential can be improved due to higher efficiency and prolonged longevity of the canopy. Gatti et al. (2016) investigated the dynamics of the annual cycle in mature potted cv. Sangiovese grapevines by applying either standard winter pruning (SWP) or late and very late winter pruning (LWP, VLWP) performed when apical shoots on the unpruned canes were at the stage of 2 or 6 unfolded leaves, respectively. In their trial, vegetative growth, phenology and canopy net CO_2 exchange (NCER) was followed throughout the season.

Despite LWP and VLWP inducing a bud-burst delay of 17 and 31 days vs. SWP, the delay was fully offset at harvest for LWP and was reduced to 6 days in VLWP. LWP showed notably higher canopy efficiency as shorter time was needed to reach maximum NCER/leaf area (22 days vs 34 in SWP), highest maximum NCER/leaf area (+37% as compared to SWP) and higher NCER/leaf area rates from veraison to end of season (Figure 4). As a result, seasonal cumulated carbon in LWP was 17% higher than SWP. A negative functional relationship was also established between the amount of leaf area removed at winter pruning and yield per vine and berry number per cluster. This preliminary study indicated that proper winter pruning date should be timed so as not to exceed the stage of two-three unfolded leaves and such an outcome has been confirmed in several other studies.(Frioni et al. 2016, Moran et al 2017, Petrie et al. 2017, Silvestroni et al. 2018). Palliotti et al. (2017) found that, after a late hand-finishing of mechanically pre-pruned vines (double pruning), two populations of shoots and fruits, with distinct phenological dynamics, were carried on the same vines. However, the applicability of late pruning is potentially limited by the concurrent reduction of vine yield that most of the aforementioned studies report together with the ripening delay. The later the pruning, the higher the reduction of shoot fertility and vine productivity (Frioni et al. 2016, Palliotti et al. 2017, Silvestroni et al. 2018). On the other hand, in different environments and cultivars, this yield reduction was not consistent among vintages and seemed to be bearable (Moran et al. 2017, Petrie et al. 2017). Overall, all available studies agree that late pruning can be an effective technique to delay ripening, but more knowledge is needed to adequately calibrate it to the vineyard/environment and to avoid/reduce yield losses.

3. Conclusions

The array of adaption techniques presented above and aimed to decompress ripening in warm environment is solid and reliable. Moreover, all proposed solutions are easily mechanizable and, as a consequence, economically sustainable. However such solutions, albeit valid in the short term, are probably not sufficient if a mid-term strategy of adaptation to global warming is pursued. From one side, growers should seriously consider any cultural or management factor that might aggravate annual cycle compression and remove it; under-cropping and excessive vine devigoration are still very common features in vineyards. From the other side, a mid-term strategy must consider relocation of vineyards (e.g. planting at higher altitudes or on less exposed slopes) as well as improved genetic material such truly drought tolerant or more invigorating rootstocks as well as more productive clones.

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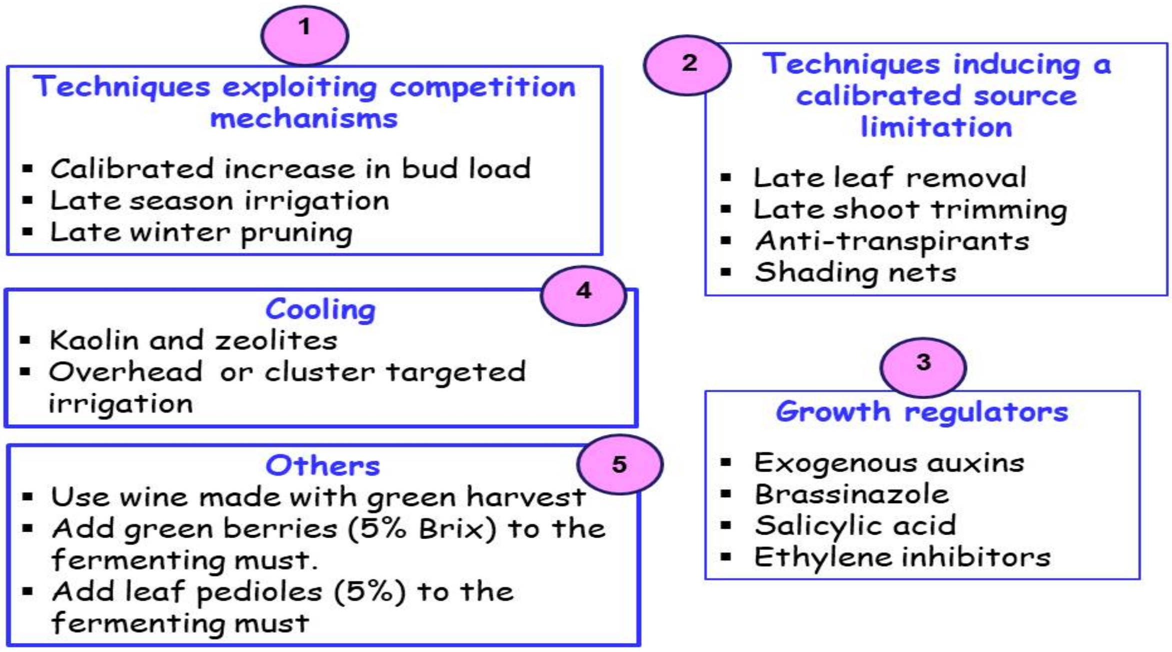

Figure 1: Different categories of techniques suitable to decrease the pace of ripening in the grapevine.

Figure 2: Left: Mechanical apical to the clusters leaf removal performed post-veraison in a Sangiovese vineyard.

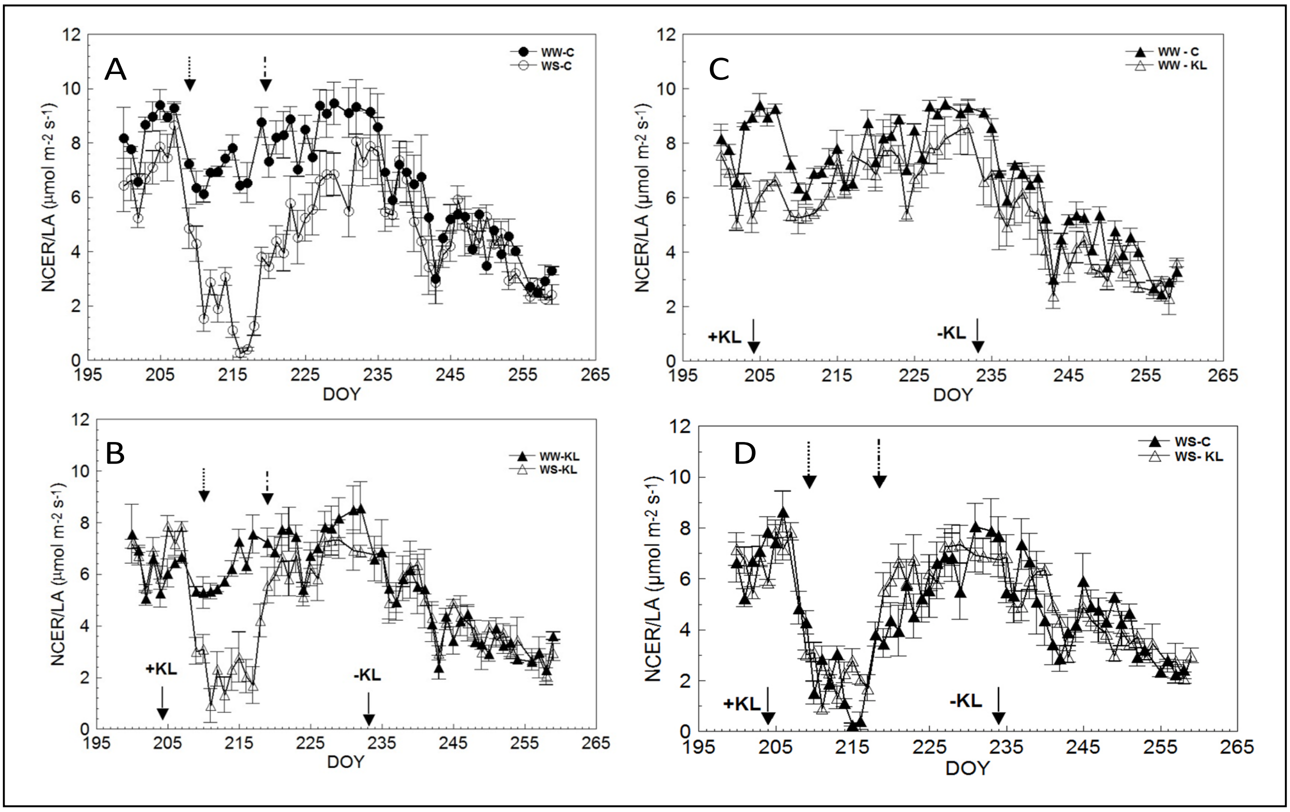

Figure 3: Seasonal progression of whole canopy net CO_2 exchange rate (NCER) per unit of leaf area (LA) measured in potted Sangiovese grapevines sprayed with KL or left unsprayed. –KL indicates the date of kaolin wash off. Sprayed and unsprayed vines were also subjected to a cycle of water stress (WS) vs. well-watered vines (WW). Dotted arrow indicates beginning of stress, dashed arrow indicates re-watering. Different panels refer to the 4 possible treatment combinations. From Frioni et al., 2019, in press.

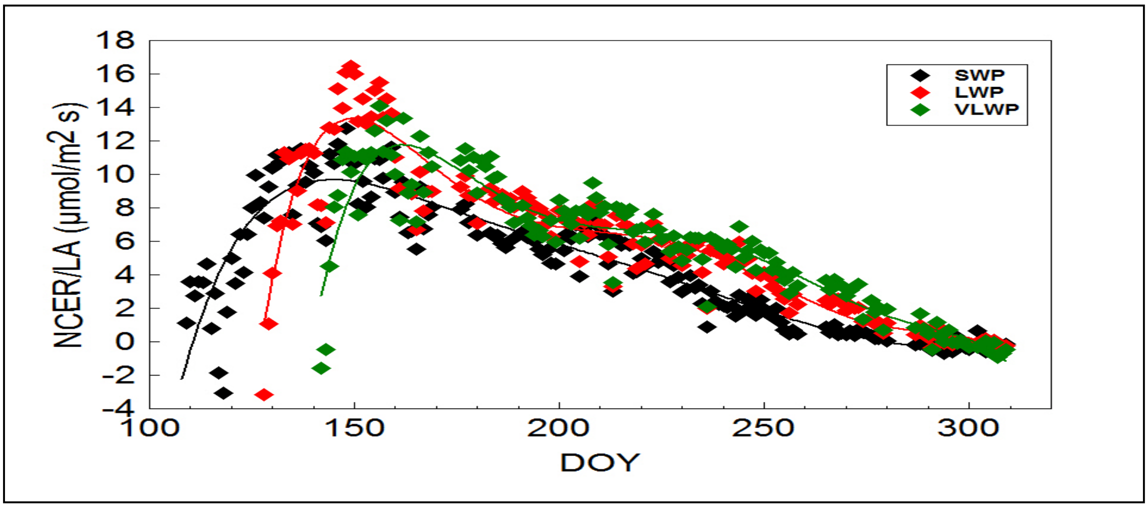

Figure 4:Seasonal trends of daily mean canopy net CO_2 exchange rate per unit leaf area (NCER/LA, µmol/m^2 s) measured in SWP (●), LWP (∘) and VLWP (Δ). Each data point is the mean of four vine replicates. For each treatment, data were fitted by a six order high precision polynomial curve yielding R^2 = 0.85 in SWP, R^2 = 0.89 in LWP and R^2 = 0.87 in VLWP. SWP = standard winter pruning; LWP = late winter pruning; VLWP = very late winter pruning.