Alcohol level reduction in wine

OENOVITI INTERNATIONAL network

organisation and contact
Pierre-Louis Teissedre - œnodoc@u-bordeaux2.fr
Tél. +33 (0)5 57 57 58 53
http://www.oenoviti.univ-bordeauxsegalen.fr
Institut des Sciences de la Vigne et du Vin
Faculté d'œnologie - Université Bordeaux Segalen
210 Chemin de Leysotte - 33882 Villenave d'Ornon cedex - France

Secretariat
Charlotte Bondu
œnodoc@u-bordeaux2.fr

isbn
2-915883-11-4
ean
9782915883114

Conception graphique/Graphc Design
Vigne et Vin Publications Internationales - Marylène Perreaud
edition@vigne-vin.com

Imprimé par/*Printed by*
Copy-Media (Mérignac - 33 - France)

Crédit photos/*Photo credits*
Emmanuel Baugier© - Fotolia©

Dépôt légal/*Legal deposit*
3e trimestre/*3rd trimestre 2013*

Alcohol level reduction in wine

OENOVITI INTERNATIONAL Network

Session I - Potential reduction in alcohol levels and viticulture

Viticultural strategy to reduce alcohol levels in wine

Vittorino Novello[1,*] and Laura de Palma[2]

[1]Dipartimento di Scienze Agrarie, Forestali e Alimentari, Università di Torino, Via L. da Vinci 44, 10095 Grugliasco TO, Italy
[2]Dipartimento di Scienze Agrarie, degli Alimenti e dell'Ambiente, Università di Foggia, Via Napoli 25, 71121 Foggia, Italy

Abstract: Full-bodied and deeply colored red wines are presently the most appreciated and prized. Well-ripe grapes normally have a high glucidic content that gives highly alcoholic wines. Moreover, global temperature is increasing leading to advance in berry maturation and increase of sugar accumulation; this fact enhances even more the average wine alcohol content. Due to the consumer concern about the effects of high alcohol wine drinking, several producers have started to offer low alcohol wines. This type of wines can be produced by reducing alcohol in winery or by reducing sugar accumulation in berries. Within the last approach, different strategies have been suggested: selecting specific varieties or clones, increasing crop load, shading bunches, choosing proper irrigation techniques, modulating source-sink relationships by removing leaves or topping shoots, applying anti-transpirant to leaves or plant growth regulators to grapes. The results obtained from many studies are not univocal and are likely affected by the interaction between genotype and environment and by the extent to which each technique is applied.

Keywords: sugar accumulation**,** genotype, source-sink relationship, photosynthetic limitation, plant growth regulators

Introduction

Full-bodied and deeply colored red wines are presently the most appreciated and prized. The obtaining of this wine style involves a high phenol extraction from full-ripe grapes. Less ripe grapes are richer in herbaceous aromas, show a lower anthocyanin and proanthocyanidin extractability from berry skins and a higher proanthocyanidin extractability from seeds; on the whole, they tend to give excess of astringency and of herbaceous aromas in wines (Ó-Marques *et al*., 2005; Fournand *et al*., 2006).

Well-ripe grapes normally have a high glucidic content and give highly alcoholic wines. It is provable that, on average, wines have gradually increased alcohol content in the last decade.

A high wine alcohol content has negative effects on human health and, presently, is not appreciated by a wide part of consumers that prefer drinking light and responsibly (Salamon, 2006), thus it discourages wine consumption.

Moreover, ethanol excess may exert detrimental effects on must fermentation and sensory property perception (Bisson, 1999; Fischer and Noble, 1994).

In addition, it is thought that the global warming could alter grape composition (Schultz and Jones, 2010) increasing berry sugar content and final alcoholic level in wines. It is well known that elevate temperatures during berry ripening induce faster pulp maturation and enhance must total soluble solids and pH.

Another problem related to a high temperature regime during berry ripening is the greater difficulty to harvest grapes at the most suitable aromatic and phenolic maturity; this fact leads to obtain not well-balanced wines. All the effects of global warming may impact even more in agro-environmental conditions where water depletion is more effective, such as in the case of non-irrigated hilly vineyards, vines on sandy and shallow soils, high plant density (Williams, 2012).

These considerations stimulate a greater attention for strategies directed to reduce alcohol level in wine.

This type of wines can be produced by reducing alcohol in winery or by reducing sugar accumulation in vineyard. This latter approach concerns the use of some viticultural techniques.

Contact author : vittorino.novello@unito.it

1. Revisiting basic viticulture techniques

Within vineyard management, the most obvious strategy to reduce wine alcohol level is to lower grape sugar content by increasing yield. Grape yield may be increased by enhancing the bud load, lowering the cluster thinning and choosing a vigorous rootstock. However, the yield increment should be carefully assessed and modulated in order to limit possible detrimental effects on wine quality. Part of consumers presently asks wines not only less alcoholic than in the past, but also less structured, thus, possibly, a new equilibrium between fruit quality and quantity should be individuated. Basing on studies carried out by Kliewer and Dokoozlian (2005) it is easy to predict a reduction of berry sugar accumulation in vineyards having a high unitary grape yield that is often joint to a low leaf area/grape weight ratio (less than 0.8 and 0.5 m^2/kg, respectively, for VSP trained vines and for vines trained to horizontal or divided canopy).

On the other hand, vineyard strategies looking at reducing shoot vigour and obtaining small berries and clusters as well as grapes rich in phenols are also thought to be useful to produce low alcohol wines, since they are capable to provide a good quality grape at a lower maturity level in terms of sugar concentration. These strategies include the choice of a proper irrigation management, pruning intensity and new genotypes (Clingeleffer, 2007).

As concerns irrigation, increase of water supply may cause dilution of sugars, but also that of phenols. On the other hand, deficit irrigation from berry-set to veraison does not seem able to induce a vine stress apt to limit berry sugar accumulation (Cooley *et al*., 2005). Nonetheless, among several irrigation treatments experimented in a warm-dry climate, the applying of water supply only from veraison to harvest, calculated by ET_C using 0.6 K_C, proved to reduce sugar accumulation without modifying phenol composition and wine quality in Cabernet Sauvignon (Fernandez *et al*., 2013). Generally speaking, late irrigation water supply could be a strategy useful to resume shoot growth in the central phase of berry sugar accumulation in order to drive more photosynthates to the new vegetation and, thus, to reduce photosynthates available for the bunches.

As for pruning systems, minimal pruning, that greatly increases bud load and shoot number per vine, is known to stimulate some compensatory behaviors resulting in numerous little and loose bunches spread over a large canopy and well lighted, having small berries richer in skin phenols than usual and thus harvestable at a lower sugar concentration (Clingeleffer, 2007). Never-theless, European viticulture is still quite reluctant to abandon the traditional pruning systems.

Among rootstocks, low-to-moderate vigour genotypes have been proposed in Australia to produce grapes for low alcohol wines. An example of their potential effect is given by the genotypes of the Merbein series: compared to traditional rootstocks, they are able to stimulate the improving of colour and phenolics by about 20 % in Shiraz grapes harvested at maturity level lower by 1.5 °Brix than usual (Clingeleffer, 2007).

The searching of new grape varieties characterized by low berry sugar accumulation and, at same time, by optimal grape flavour and colour requires long and elaborated studies. Australian breeding work obtained new varieties, adapt to warm climate, that compared to Cabernet Sauvignon harvested at a given maturity level reached higher yield, better wine chemical composition and sensorial attributes; this is the case of Cienna, released in 2000, that has been suggested for producing low alcohol wine (Clingeleffer, 2007). Nevertheless, the searching of natural and already existing genotypes apt to produce low alcohol wines could be also considered, looking for those capable to limit sugar concentration without penalizing too much the phenol content. For example, it has been observed that some selected clones may differ in sugar accumulation dynamics (Zecca *et al*., 2013).

Apart from these techniques, the "double harvest" has been also proposed for decreasing wine alcohol level. The first harvest ("green") coincides with the normal bunch thinning performed at veraison. The must of these grapes is conserved and blended with that of grapes harvested at normal maturity. The final wines show a significant lower alcohol and pH and a higher titratable acidity, but do not differ in quality and sensory properties in comparison with those obtained by traditional wine-making (Kontoudakis *et al*., 2011; Balda and Martinez de Toda, 2013). This technique however, although starts from a viticultural practice, involves the technological aspects more than the vineyard management.

Finally, among simple growing techniques, those that allow do not expose bunches to full sunlight, such as a moderate use of leaf removal in the fruit zone and/or the choice of training systems apt to protect grape from direct solar radiation (such as pergola, free cordon, GDC), could be also reconsidered providing the assessing of proper conditions apt to modulate the grape yield/quality balance.

2. Modulating source-sink relationship and reducing photosynthetic activity

The source-sink relationships, based on the ratio between the photosynthesizing leaf surface and the fruit mass that attracts a great portion of photoassimilates, are considered of fundamental importance in modulating grape ripening and quality. For example, it is well known that by limiting leaf area at berry-set it is possible to reduce the final berry size and to improve the berry composition (Ollat and Gaudillère, 1998), and that the fruit thinning reduces the level of competition for metabolites improving the final fruit quality.

However, it is to consider that either shoot or cluster thinning may reduce the grape yield and, thus, may increase sugar accumulation in maturing bunches (Dokoozlian and Hirschfelt, 1995; Sun *et al*., 2011). Moreover, cluster and shoot thinning may result in more “fruity” wines, but they may also penalize tannin extractability in some varieties (Sun *et al*., 2012).

On the other hand, changes of leaf-to-fruit ratio may reduce the velocity of berry maturation and the final sugar content. Stoll and collaborators (2010) proved that, by topping severely vine shoots at berry-set (leaving 6 leaves per shoot) it is possible to slow down Riesling grape maturation by 20 days and to cut final sugar accumulation by about 4 °Brix. Severe shoot topping (just over clusters) after berry-set, that induced a relevant reduction of leaf area/grape weight ratio, slow down maturation and significantly reduced sugar content, bunch and berry weight in cvs Grenache and Tempranillo; however, total polyphenol and anthocyanin concentration in the must were penalized (Balda and Martinez de Toda, 2011). Filippetti and collaborators (2011), by late-topping Sangiovese shoots one week after veraison, obtained a good lowering of must sugar concentration without modifying pH, organic acid and anthocyanins concentration, skin and seed tannins content.

The leaf removal technique is effective in modulating source-sink relationship. Leaf removal above cluster zone (-36 %) one month after veraison reduced leaf-to-fruit ratio by 41 % and proved to slow down maturation of Sangiovese grape and to lower sugar concentration and wine alcohol level (-0.6 %) (Palliotti *et al*., 2013). Post-veraison leaf removal at distal canopy portion of Sangiovese and Montepulciano vines (removing respectively 60 % and 29 % of vine leaf area) reduced leaf/fruit ratio at harvest by 38 % (Sangiovese) and 16 % (Montepulciano) without affecting bunch and berry weight, must total acidity and pH, but lowering sugar concentration (-0.7 °Brix) in both varieties; however, also final Montepulciano anthocyanin and polyphenol concentration were reduced (Lanari *et al*., 2013). Leaf removal of eight basal leaves, at fruit-set, lowered significantly total soluble solids in the white grapes of cv Loureira (Freire *et al*., 2013). In Negroamaro vines, the removal (at berry pea-size) of main leaves and lateral shoots from the basal node to the second node over the clusters (eliminating about 63 % of vine leaf area), reduced grape yield (-14 %), improved wine total polyphenols (+17 %), anthocyanins (+15 %) and colour intensity (+16 %) compared with the regular thinning of 50 % main leaves and laterals along the entire canopy. Moreover, the first treatment lowered total flavonoids (-22 %) and proanthocyanidins (-16 %), and reduced berry total soluble solid (-1 °Brix) and wine alcohol but only by 4 %. Differences in the type of removed leaf, canopy microclimate, leaf ecophysiological functioning and leaf-to-fruit ratio accounted for these results (de Palma *et al*., 2010). In Nebbiolo grape fruit zone leaf removal and bunch shading improved berry phenol composition (North-West Italy), but did not influenced berry sugar accumulation in comparison to the control (Guidoni *et al.*, 2008; Chorti *et al.*, 2010).

As concerns the influence of the training system, Sylvoz and Lyre have been found use- ful to reduce potential alcohol in Sousón grapes, likely due to the increase of shoot vigour, vine productivity and bunch shading normally associated to these training systems; Lyre induced similar results also in Godello and Loureira grapes (Diaz-Losada *et al.*, 2013).

3. Photosynthetic limitation

The limitations of photosynthetic rate per leaf area unit act as a reduction of “active” leaf area, although leaves are not removed.

The application of shade nets over the vine canopy reduces the photosynthetic photon flux at the leaf surface available for photosynthetic process. According to the net colour and density different shading levels may be obtained. Measuring diurnal rates of leaf net CO_2 uptake per leaf area unit in Sangiovese vines exposed at 100 %, 60 % and 30 % of full sunlight, it was observed, at flowering, a relevant difference between the two extreme treatments. At harvest, vine productivity decreased only by 14 %, but sugar content decreased by 2 3% (from 21.9 °Brix to 16.8 °Brix) (Palliotti *et al.*, 2012).

Anti-transpirant canopy sprays obtained by distillation of conifer resins (such as those containing ‘pinolene’, a product having 1-*p*-menthene as active compound) are able to reduce the leaf CO_2 influx. After spraying, the product evaporates in few hours leaving the leaves covered by a thin transparent layer that limits the rate leaf gas exchange. Rates ranging from 30 % to 70 % of those of control vines have been observed for a period of 40-50 days. After the product is degraded, leaves are able to recover their functionality. Investigations performed since 2008 proved that post-veraison anti-transpirant treatments may induce a significant reduction of must sugar concentration and, hence, of wine alcoholic level, regardless of the cultivar and the vine productivity. In Italy, trials were carried out on Sangiovese, Tocai rosso, Trebbiano toscano and Grechetto producing from 7 to 32 t/ha of grapes. However, anti-transpirant treatments may induce some detrimental effects on phenolic content, mostly in black-berry varieties and especially for anthocyanins, while total polyphenol content seems less affected. This effects are not desirable for aged red wines, but they could be acceptable for rosé and Beaujolais type of wines or for base wines to blend with others richer in color and phenolic compounds (Palliotti *et al.*, 2008; 2010; 2013). Similar results were obtained by Tittmann and coauthors (2013) in Riesling and Müller Thurgau grapes grown either in greenhouse or in open field.

4. Plant growth regulator treatments

Several hormones, such as abscisic acid and ethylene, are known to have a direct influence on the maturation processes, including colour development, while the auxin level is normally reduced when the fruit ripening begins. Hence, among techniques aiming at slow down grape maturation, the use of plant growth regulators may be proposed.

According to research of Davies and collaborators (1997), dipping Shiraz bunches for 30 seconds in benzotriazole-2-oxaloacetic acid (BTOA) 6 and 8 weeks after blooming is able to delay the evolution of physical-chemical changes related to maturation: increase of berry weight, anthocyanin and hexose accumulation and abscisic acid concentration, and degradation of chlorophyll and organic acids. The expression of genes typical of the pre-veraison stage continued for an extensive period, while that of genes typical of the ripening period was delayed.

Some cytokinins, such as CPPU (forchlorfenuron), applied at pre-veraison stage, are able to reduce total soluble solid concentration and berry skin colour; berry weight and juice total acidity are increased (Han and Lee, 2004).

Pre-veraison auxin treatments (1-naphtha-leneacetic acid) proved to delay Shiraz berry ripening in terms of juice sugar accumulation and skin anthocyanin content. Wine sensory characteristics did not change in comparison to the control. Hence, auxin applications may represent a technique useful to control fruit composition (Böttcher *et al.,* 2011).

5. Conclusions

Reducing alcohol levels in wine is a challenge for the next future. Viticultural strategies useful to face this problem are all those apt to reduce grape sugar content at harvest, since this is the starting point to obtain less alcohol in wine. Except for the searching of specific grapevine genotypes, these strategies are mostly based on the proper use of some growing techniques having a direct or indirect impact on the berry sugar accumulation, such as, for example, irrigation, pruning and canopy management; however, they have to be revisited in order to achieve the desired result. The use of anti-transpirants to spray on leaves and of plant growth regulators to apply on grapes may be considered as a new tools.

All the techniques limiting photosynthesis, or modifying the source-sink ratio or delaying fruit maturation may reach the goal. Nevertheless, this is not always easy to reach since grapevine has a high physiological plasticity that provides several compensatory responses acting as a buffer respect to the imposed treatments. Moreover, together with a low alcohol level, a high color intensity and a rich aromatic and phenol profile is any case required for quality wines; grapes harvested at a total soluble solid concentration suitable to produce low alcohol wines may not have enough phenols, especially in terms of anthocyans, also when they have been obtained by applying proper viticultural methods. It is easy to suppose that the best results could derive from optimizing the application of several growing techniques at the same time.

The experimental results available at the moment show often not univocal indications. This is a consequence of the fact that each viticultural thecnique may be applied at a different extent, and that the interaction between grape variety, rootsock and environment is very complex. Moreover, it is to consider that most of the presented experimental results derive from research on vineyard management not specifically devoted to the obtaining of grapes for low alcohol wines. To clarify many of the actual discrepancies in the results more specific studies on this argument should be done.

6. References

Balda P., Martinez De Toda F., 2011. Delaying berry ripening process through leaf are to fruit ratio *decrease. Proceedings of "17th International Symposium of the Giesco",* August 29th-2nd September 2011, Asti-Alba, Italy, 579-582.

Balda P., Martínez de Toda F., 2013. Decreasing the alcohol level and pH in wines by the "double harvest" technique. Ciência e Técnica Vitivinícola, Volume 28, *Proceedings 18th International Symposium GiESCO*, Porto, 7-11 July 2013, 899-903.

Böttcher C., Harvey K., Forde C.G., Boss P.K., Davies C., 2011. Auxin treatment of pre-veraison grape (*Vitis vinifera* L.) berries both delays ripening and increases the synchronicity of sugar accumulation. *Australian Journal of Grape and Wine Research*, **17**, 1–8.

Chorti E., Guidoni S., Ferrandino A., Novello V., 2010. Effect of Different Cluster Sunlight Exposure Levels on Ripening and Anthocyanin Accumulation in Nebbiolo Grapes. *Am. J. Enol. Vitic.*, **61**(1), 23-30.

Clingeleffer P.R., 2007. Viticultural practices to moderate wine alcohol content. *Proceedings ASVO Seminar: Towards best practice through innovation in winery processing*. Tanunda (SA), Australia, 17 October.

Cooley N.M., Clingeleffer P.R., Walker, R.R., 2005. The balance of berry sugar accumulation, colour and phenolic concentration under deficit irrigation strategies. *Proceedings of the Twelfth Australian Wine Industry Technical Conference*, Melbourne (Vic.) Australia, 2004, pp. 94–96.

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**, 155–1161.

de Palma L., Tarricone L., Muci G., Limosani P., Savino M., Novello V., 2011. Leaf removal, vine physiology and wine quality in cv. Negroamaro (*Vitis vinifera* L.). *Progrès Agricole et Viticole, 17th GiESCO Meeting*, Asti - Alba (CN), Italy, 29th August - 2nd September 2011, 231-234.

Díaz-Losada E., Trigo-Córdoba E., Soto-Vázquez E., Bouzas-Cid Y., Mirás-Avalos J.M., Rego-Martínez F., 2013. Effects of training system on the agronomical and enological performance of Galician grapevine cultivars. Ciência e Técnica Vitivinícola, Volume 28, *Proceedings 18th International Symposium GiESCO*, Porto, 7-11 July 2013, 578-582.

Dokoozlian N. K., Hirschfelt D. J., 1995. The influence of cluster thinning at various stages of fruit development on flame seedless table grapes. *Am. J. Enol. Vitic.*, **46**, 429-436.

Filippetti I., Allegro G., Movahed N., Pastore C., Valentini G., Intrieri C., 2011. Effects of late-season source limitation induced by trimming and antitraspirants canopy spray on grape composition during ripening in *Vitis vinifera* cv Sangiovese. *Proceedings 17th International Symposium GiESCO*, Asti - Alba (CN), Italy, 29th August - 2nd September 2011, 259-262.

Fernández O., Sánchez S., Rodríguez L., Lissarrague J.R., 2013. Effects of different irrigation strategies on berry and wine composition on Cabernet sauvignon grapevines grown in Madrid (Spain). Ciência e Técnica Vitivinícola, Volume 28, *Proceedings 18th International Symposium GiESCO*, Porto, 7-11 July 2013, 112-117.

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**, 6–10.

Fournand D., Vicens A., Sidhoum L., Souquet J.M., Moutounet M., Cheynier V., 2006. Accumulation and extractability of grape skin tannins and anthocyanins at different advanced physiological stages. *J. Agric. Food Chem.*, **54**, 7331-7338.

Freire L., Canosa P., Rodríguez-Vega I., Vilanova M., 2013. Effect of early leaf removal on yield components, must composition and wine volatiles of *Loureira* cv from NW Spain. Ciência e Técnica Vitivinícola, Vol. 28, *Proceedings 18th International Symposium GiESCO*, Porto, 7-11 July 2013, 422-425.

Guidoni S., Ferrandino A., Novello V., 2008. Effects of Seasonal and Agronomical Practices on Skin Anthocyanin Profile of Nebbiolo Grapes. *Am. J. Enol. Vitic*., **59** (1), 22-29.

Han D.H., Lee C.H., 2004. The Effects of GA3, CPPU and ABA Applications on the Quality of Kyoho (*Vitis vinifera* L. x *V. labrusca* L.). *Grape. Acta Hort*., 653, 193-197.

Kliewer W.M., Dokoozlian N.K., 2005. Leaf area/crop weight ratios of grapevines: influence on fruit composition and wine quality. *Am. J. Enol. Vitic.*, 56, 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. *Aust. J. Grape Wine Res.,* **17**, 230–238.

Lanari V., Lattanti T., Borghesi L., Silvestroni O., Paliotti A., 2013. Post-Veraison Mechanical Leaf Removal Delays Berry Ripening on ‘Sangiovese’ and ‘Montepulciano’ Grapevines. *Acta Hort.*, **978**, 327-333.

Martinez de Toda F., Balda P., 2011. Decreasing the alcohol level in quality red wines by the “double harvest” technique. *Progrès Agricole et Viticole, Proceedings 17th International Symposium GiESCO*, Asti - Alba (CN), Italy, 29th August - 2nd September 2011, 463-466.

Ó-Marques J., Reguinga R., Laureano O., Ricardo da Silva J.N., 2005. Changes in grape seed, skins and pulp condensed tannins during berry ripening: effect of fruit pruning. *Ciência Tècnica Vitivinicola*, **20**, 35-52.

Ollat N., Gaudillère J.P., 1998. The Effect of limiting leaf area during stage I of berry growth on development and composition of berries of *Vitis vinifera* L. cv. Cabernet Sauvignon. *Am. J. Enol. Vitic.*, **49**, 251-258.

Palliotti A., Poni S., Petoumenou D., Vignaroli S., 2008. Limitazione modulata della capacità fotoassimilativa delle foglie mediante antitraspiranti ed effetti su qualità e composizione dell’uva. *Atti: “II Convegno Nazionale di Viticoltura”*, Marsala 14-19 Luglio 2008. Italus Hortus 17 (suppl. n. 3), 21-26, 2010.

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. *Austr. J. Grape Wine Res*., **16**, 426-433.

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** (2), 1-15.

Palliotti A., Silvestroni O., Leoni F., Cini R., Poni S., 2013. Effect of late mechanized leaf removal to delay grape ripening on Sangiovese vines. *Acta Hort.,* 978, 301-307.

Salamon A., 2006. Techniques to achieve moderate alcohol levels in South African wine. Assignment submitted in partial requirement for the Cape Wine Master Diploma. capewineacademy.co.za.

Schultz H.R., Jones G.V., 2010. Climate Induced Historic and Future Changes in Viticulture. *Journal of Wine Research*, **21** (2–3), 137-145.

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. *Progrès Agricole et Viticole*, **127**(3), 68-71.

Sun Q., Sacks G.L., Lerch, S.D., Vanden Heuvel J.E., 2011. Impact of shoot thinning and harvest date on yield components, fruit composition, and wine quality of Marechal Foch. *Am. J. Enol. Vitic.*, **62** (1), 32-41.

Sun Q., Sacks G.L., Lerch S.D., Vanden Heuvel J.E., 2012. Impact of shoot and cluster thinning on yield, fruit composition, and wine quality of Corot noir. *Am. J. Enol. Vitic.,* **63** (1), 49-66.

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. Ciência e Técnica Vitivinícola, Volume 28, *Proceedings 18th International Symposium GiESCO*, Porto, 7-11 July 2013, 276-282.

Williams L., 2012. Potential vineyard evapotranspiration (ET) due to global warming: comparison of Vineyard et at three locations in California differing in mean seasonal temperatures. *Acta Hort*., **931**, 221-236.

Zecca O., Valentini S., Domeneghetti D., 2013. Comparison of six Gamay noir clones in a high altitude environment. Ciência e Técnica Vitivinícola, Volume 28, *Proceedings 18th International Symposium GiESCO*, Porto, 7-11 July 2013, 800-804.