

EFFECT OF CANOPY MANAGEMENT TECHNIQUES ON THE NUTRITIONAL QUALITY OF MONTEPULCIANO GRAPEVINE IN PUGLIA (SOUTHERN ITALY)

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Abstract

Aims: Tests were carried out to assess the effects of early defoliation, cluster thinning and cluster cutting on the basic and nutritional composition of musts and wines of *Vitis vinifera* L. cv. Montepulciano.

Methods and results: Both production and quality variables of the musts were evaluated. Antioxidant activity was determined on berries and on wines, as were the phenol and anthocyanin concentrations. The wines were compared by sensory evaluation. The results attested to a positive effect of the treatments on grape composition and on antioxidant activity in the berries.

Conclusions: The tested treatments (*DP* = early defoliation; *D3* = cluster thinning 30%; *D5* = cluster thinning 50%; *T3* = cluster cutting 30%; *T5* = cluster cutting 50%) increased both the soluble solids and the pH of the musts and enhanced the nutritional quality (based on antioxidant concentration) of both the grapes and the wine.

Significance and impact of the study: The adopted techniques may be useful in cases in which yield control is required and/or the composition of the musts and wines needs to be modified based on the concentration of sugars in the berries. However, the variable response of the vines to the various techniques suggests that each cultural practice be evaluated in relation to specific oenological objectives.

Key words: early defoliation, cluster thinning, cluster cutting, antioxidant activity, sensory analysis

Résumé

Objectifs: Des essais ont été effectués pour évaluer les effets de la défoliation précoce, l'éclaircissage des grappes et la coupe des grappes sur la composition nutritionnelle de base des moûts et des vins de *Vitis vinifera* L. cv. Montepulciano.

Méthodes et résultats: La production et les variables de la qualité des moûts ont été évaluées. L'activité antioxydante a été déterminée sur les baies et sur les vins, ainsi que les concentrations de phénol et d'anthocyanes. Les vins ont été comparés par analyse sensorielle. Les résultats témoignent d'un effet positif des traitements sur la composition des raisins et sur l'activité antioxydante dans les baies.

Conclusions: Les traitements testés (*DP* = défoliation précoce; *D3* = éclaircissage des grappes de 30%; *D5* = éclaircissage des grappes de 50%; *T3* = coupe des grappes de 30%; *T5* = coupe des grappes de 50%) ont augmenté à la fois les solides solubles et le pH des moûts et ont amélioré la qualité nutritionnelle (basée sur la concentration d'antioxydant) à la fois des raisins et du vin.

Signification et impact de l'étude: Les techniques adoptées peuvent être utiles dans les cas où le contrôle du rendement et/ou la modification de la composition des moûts et des vins en fonction de la concentration des sucres dans les baies est souhaité. Cependant, la réponse variable des vignes aux différentes techniques suggère que chaque pratique culturale doit être évaluée par rapport à des objectifs oenologiques spécifiques.

Mots clés: défoliation précoce, éclaircissage des grappes, coupe des grappes, activité antioxydante, analyse sensorielle

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INTRODUCTION

Attaining consistency in fruit composition in winegrapes is a major challenge. This may be due to various factors such as the cultivation site (e.g., microclimate and type of soil) and the use of unsuitable vineyard management techniques (Scaglione *et al.*, 2001). This challenge arises more frequently within similar environmental conditions, when certain training systems generally noted for their high productivity (tendone, etc.) are adopted (Reynolds and Vanden Heuvel, 2009). During the planning stages, the agronomist should bear in mind the climatic and pedological conditions of the site and set up the vineyard so as to maximize the quality of the grapes, and he should make the technical choices to achieve the oenological objectives (training system, type of pruning, planting distance).

Once the vineyard is in full production, in cases of plant imbalance in which an enhancement of grape quality and/or a reduction of excess yield are required, a wide range of options needs to be explored. Among these, canopy management techniques (early leaf removal, cluster thinning and cluster cutting) should be considered. As regards early leaf removal, the information available is limited to the effect of the technique on berries (Hunter *et al.*, 1991; Ollat and Gaudillère, 1998; Di Profio *et al.*, 2011) and grape and wine composition (Poni *et al.*, 2006; Bavaresco *et al.*, 2008; Holt *et al.*, 2008; Kemp *et al.*, 2011), while there is little information on the effect of the technique on the sensory characteristics of the wine (Tardaguila *et al.*, 2008; Lohitnavy *et al.*, 2010) or on the antioxidant concentration in the berry (Prajitna *et al.*, 2007). Similarly, with respect to cluster thinning, there is information on the effect of the technique on crop load, the sugar concentration in must (Shim *et al.*, 2007; Gil-Munoz *et al.*, 2009; Valdes *et al.*, 2009) and the chromatic characteristics of wine (Shim *et al.*, 2007; Valdes *et al.*, 2009; Gil-Munoz *et al.*, 2009) on a few cultivars, but there is insufficient information on the effect of the technique on the evolution of antioxidants in the berries (Prajitna *et al.*, 2007) and on the sensory characteristics of the wines. Finally, there is no information on the effect of cluster cutting, which consists in removing the distal part of the cluster.

The Montepulciano cultivar used for this trial was chosen because it is widely cultivated in southern Italy (Apulia and Calabria) and central Italy (Abruzzo). The main objective of our research was to study the effect of canopy management techniques on both the possible improvement in the quality of Montepulciano wines and the control of excess production. We studied a vineyard known for its excess production (due both to the climatic and pedological characteristics of the site and to the training system) where the above-mentioned canopy

management techniques had been carried out. Another objective of this research was to investigate the effect of the techniques on the antioxidant concentration in the berry and finally to further our knowledge of the effect of the techniques on the sensory characteristics of the wines. It has already been noted that several agronomic factors can influence the antioxidant capacity of crops. In particular, Lee and Kader (2000) reported that pruning and thinning vines determine their crop load (Reynolds and Vanden Heuvel, 2009), which in turn affects fruit size and composition, including vitamins (Lee and Kader, 2000). The plant may sometimes gain in quality through the adoption of management techniques (green pruning), which can make a valid contribution.

The concentration of flavonoids as phenolic compounds in *Vitis* species depends on the cultivar and is influenced by viticultural and environmental factors (Downey *et al.*, 2006). In this research, in order to study the effect of canopy management on nutritional quality, we investigated the antioxidant capacity, total phenol content and anthocyanin content in the berries and wines obtained. Grapes are known to contain a large amount of different phenolic compounds in skins, pulp and seeds, that are partially extracted during winemaking. These compounds have an important role in determining the quality of red cultivars (Jackson, 1994). Once grapes have been crushed and prior to the start of alcoholic fermentation, several reactions take place that involve some of the above molecules (especially anthocyanins, catechins and procyanidins), resulting in the formation of new polymeric pigments (Singleton *et al.*, 1978). Depending on the type of grape, wine composition may vary widely according to the concentration and the nature of the phenolics (Ribéreau-Gayon *et al.*, 2000).

MATERIALS AND METHODS

1. Experimental design

The experiment was conducted in 2007 in a commercial vineyard in Lucera near Foggia in Apulia (southern Italy, lat. N: 41° 29' 99", long. E: 15° 21' 10") on 10-year-old Montepulciano (*Vitis vinifera* L.) grapevines grafted onto 1103P. The vines were tendone-trained and Guyot-pruned to 40 nodes per vine with a spacing of 2.5 x 2.5 m. Rainfall was measured using a meteorological station placed in the vineyard. From 1st April to 30th October 2007, total rainfall was 178 mm. From 1st April to 30th September 2007, 15 irrigations were carried out (every ten days) distributing a total of 1500 m³ of water. The vines were subdivided into six treatments: *C* = untreated; *DP* = early defoliation; *D3* = cluster thinning 30 %; *D5* = cluster thinning 50 %; *T3* = cluster cutting 30 %; and *T5* = cluster cutting 50 %. Each canopy management treatment was applied in the

spring on three replicate groups of 30 contiguous vines. A completely randomized block design was used in the experiment.

At harvest, for each treatment, a sample of 100 berries, replicated three times, was used to determine various levels in the musts: soluble solids, titratable acidity (TA), and pH. Another sample of 100 berries (replicated three times) was used to analyze the antioxidant activity, phenols and anthocyanin concentration in order to check the evolution of antioxidants during berry growth on four dates: 8th August, 8th September, 18th September and 4th October (harvest time).

2 Canopy management treatments

When the shoots reached the “full” stage H (separate flower buttons) of Baggiolini (1952), the assigned vines were submitted to *DP*, which consisted of removing the first six main basal leaves from each shoot. When the shoots reached the “full” stage L (veraison), the assigned vines were submitted to a cluster thinning treatment, which consisted of removing 30 % (*D3*) or 50 % (*D5*) of the clusters. Similarly, when the shoots reached the “full” stage L (veraison), the assigned vines were submitted to a cluster cutting treatment, which consisted of cutting 30 % (*T3*) or 50 % (*T5*) of the distal part of the clusters. The control vines were not submitted to any canopy management treatment.

3. Winemaking

At harvest, for each treatment (*C*, *DP*, *D3*, *D5*, *T3* and *T5*), a sample of 200 kg of grape, replicated three times, was harvested and transported to the winery for vinification. The crushed and destemmed grapes were distributed in 18 100-L tanks (three replications per treatment). Winemaking in red proceeded in two stages: maceration for two days followed by alcoholic fermentation for six days, then racking and pressing. Prior to bottling, the wines were placed in cold storage for one week in order to stabilize them and then were slightly sulphited (20 mg/L) to preserve them until analyses.

4. Chemical composition measurements

Soluble solids content (°Brix) and TA (g/L) of the must were determined periodically by classical analyses (OIV, 1990) using a refractometer (Mettler Toledo RM 40). TA was measured by titration with 0.25N NaOH to an end point of pH 8.2. The pH of the must obtained from the crushing of the berries was measured with a pH meter (Mettler Toledo S 80).

The ripening date was established on the basis of must characteristics, when the soluble solids content was between 22 and 24 °Brix, pH between 3.40 and 3.70, and TA between 8.0 and 9.0 g/L. At harvest, the number and

weight of clusters, berry weight and yield per vine were recorded, and the soluble solids concentration, pH and TA in berries were measured. The sampling and quantitative analyses were carried out by using methods described by other authors (Carillo *et al.*, 2011), while the physical and chemical analyses on must were carried out by referring exclusively to official methods (Lotti and Galoppini, 1980). In the vineyard, the entire production of the plants from each treatment was weighed and the number of clusters counted. In order to measure the main chemical variables, three or four clusters per treatment replicate were sampled and taken to the laboratory. The berries were then separated from the clusters; 300 berries randomly taken from the clusters were crushed, separating the must from the skin and the pulp.

5. Skin antioxidant analyses

Skin antioxidant activity was evaluated by the ABTS⁺ (2,2'-azino-bis-(3-ethylbenzothiazoline-6-sulphonic acid) diammonium salt) method as described by Re *et al.* (1999) on the samples obtained using the procedure for anthocyanin extraction (Gennaro *et al.*, 2002). Briefly, 1.5 g of skins were homogenized in 5 mL of methanol (0.1 % HCl) at room temperature for 10 min. The extract was filtered and used for measuring antioxidant activity and total anthocyanins. In particular, radical scavenging of the skin extracts was determined by using 100 µl of 1 : 100 diluted samples. The stock solutions included 7.4 mM ABTS⁺ solution and 2.6 mM potassium persulphate solution. The working solution was then prepared by mixing the two stock solutions in equal quantities and allowing them to react for 12 heures at room temperature in the dark. The solution was then diluted by mixing 1 mL ABTS⁺ solution with 60 mL methanol to obtain an absorbance of 1.10±0.02 units at 734 nm using a spectrophotometer. Fresh ABTS⁺ solution was prepared for each assay. Skin extracts (100 µL) were allowed to react with 1000 µL of the ABTS⁺ solution for 2.5 min in dark conditions. Then the absorbance was taken at 734 nm using a spectrophotometer. The standard curve was linear between 25 and 600 µM Trolox. Antioxidant activity was expressed as mmol of Trolox equivalents/100 g of fresh weight (FW) sample (TEAC). Additional dilution steps were performed if the measured ABTS was over the linear range of the standard curve.

Total anthocyanins were determined spectrophotometrically using the pH shift method. Anthocyanins were quantified using malvidin-3-monoglucoside as standard (ϵ 516 nm = 4.48 mM⁻¹ cm⁻¹) and expressed as malvidin equivalents (mmol g FW⁻¹).

6. Pulp antioxidant analyses

Total phenol concentration and the antioxidant activity of hydro alcoholic extract were measured on the pulp.

An extraction was made on 1 g of pulp with 10 mL of methanol/water (70 : 30 v/v) by sonication at room temperature for 30 min. The mixtures were centrifuged at 4000 rpm, filtered through Whatman filter papers (Maidstone, England) and then used for antioxidant analysis. Antioxidant activity was measured using the ABTS⁺ method using 100 µL of 1:10 diluted samples, as described in the skin antioxidant analysis, and expressed as TEAC. Total phenols were determined on the same extract (diluted 1:10) using the Folin-Ciocalteu method (Singleton and Rossi Jr, 1965) and expressed as mg of gallic acid/100 g of FW sample.

7. Wine antioxidant analyses

The wines were analyzed for anthocyanins and for antioxidant activity. Antioxidant activity was measured using a spectrophotometric method based on radical cation decolourization through the agency of antioxidant compounds: 100 mL of diluted wine samples were added to 1 mL of ethanolic solution of ABTS⁺ as reported by Re *et al.* (1999), then the absorbance of the reaction mixture was measured at 734 nm after 2.5 min. Antioxidant activity was expressed as mmol of Trolox/L of samples. Total phenols were measured on 0.5 mL of wine diluted to a volume of 5 mL with 10 % ethanol; each diluted sample was analyzed for total phenols using the Folin-Ciocalteu analysis using the spectrophotometric assay described previously.

8. Wine sensory analysis

The sensory evaluation of the wines obtained was performed by a panel of 10 tasters (3 women and 7 men; winemakers and oenology teachers) from the Faculty of Oenology in Tarragona (URV, Spain), approximately 3 months after finishing alcoholic and malolactic fermentation. All of the panellists were members of a wine tasting group and had a long experience in identifying differences in wines that are produced in research trials performed at the university. We tasted experimental wines from the 2007 vintage to the present time in a wine tasting room belonging to the Faculty of Oenology. The results of the panellists were submitted to ANOVA analysis and the averages compared by Fisher's test at $p \leq 0.05$.

A number of sensory evaluation methods have been used to assess the quality of food and beverages (Lawless and Heymann, 1997), with expert panels usually consisting of 8 to 15 people (Noble *et al.*, 1984; Holt *et al.*, 2008; Parpinello *et al.*, 2009). Zamora and Guirao (2004) validated the better training for participating in a wine tasting panel by comparing between trained and expert groups. Of 17 attributes evaluated, 13 turned out significant for wine discrimination among experts,

whereas this number was only of 7 among the trained assessors. We adopted a check sheet proposed by Vedel *et al.* (1972), a classical tasting chart used by the *Office International de la Vigne et du Vin* (OIV) in wine competitions. The Vedel chart is a precise and complete model. In fact, the duration of the evaluation process of each wine is short, therefore rendering testing for specific properties both easy and rigorous. The Vedel tasting sheet has also been adopted by the INAO (*Institut National d'Appellations d'Origine*) in France. The Vedel score categories are so different from each other that it clarifies the differences between samples. Panellists rated the wine for the following aspects: colour (intensity and clarity), smell (intensity and quality), taste (intensity and quality), and harmony (global evaluation of the wine's balance between the different sensory aspects detected). In all, 7 variables were evaluated and scored.

All wine attributes were scored according to a numerical scale inversely proportional to the quality of the single variable evaluated. The total score of each wine, obtained by summing all the variables, allowed the wines to be classified as follows: « poor »; « acceptable », « good », « very good » or « excellent ». In the preliminary session, all participants assessed the control treatment before tasting the samples in order to discuss the specific characteristics of the Montepulciano red variety. Following the description of the reference sample, tasters carried out independent ratings of the attributes with the wines presented in a completely randomized order. After tasting, any useful comment on the understanding of the colour, aroma, mouthfeel and harmony of the wines was allowed. The duration of the session was 90 min. In addition, due to the importance of phenolics in the wine structure and mouthfeel quality for red grape varieties, we performed a second tasting evaluation, specifically to determine the intensity of tannin astringency perceived in the oral cavity. The scale used for astringency ranged from 1 (low) to 5 (high).

9. Statistical analysis

All the test results were submitted to analysis of variance (ANOVA) and the differences highlighted with the Fisher's test. The means were compared using the SPSS 17.0 program for Windows (SPSS Inc. Chicago, IL USA) with a level of significance of $p \leq 0.05$.

RESULTS AND DISCUSSION

1. Yield components

The treatments generally influenced the main yield components. Early defoliated vines had lower yield compared with the non-defoliated control vines (data not reported). A similar effect has been observed on other cultivars such as Cabernet- Sauvignon (Ollat and

Gaudillère, 1998) and Sangiovese (Intrieri *et al.*, 2008). As has been observed on Tempranillo and Syrah (Gil-Munoz *et al.*, 2009), cluster thinning reduced yield in *D3* and *D5* compared with the control. A similar response was observed for cluster cutting treatments, which showed appreciable yield reductions compared with the untreated control (data not reported). As expected, there was an appreciable reduction in cluster weight for all the treatments as compared to the control. In general, our results seem to confirm what has been reported by others (Valdes *et al.*, 2009; Gil-Munoz *et al.*, 2009). Except for *D3* and *D5*, reductions in berry weight were observed for all the treatments compared to the control (data not reported). Similar results have been reported by other authors (Ollat and Gaudillère, 1998; Poni *et al.*, 2006).

2. Fruit composition

The treatments generally achieved desirable responses on almost all the fruit composition variables tested. As with the Kyoho grape (Shim *et al.*, 2007), cluster thinning increased the soluble solids content of musts in treatments *D3* and *D5* compared to the control. A similar response was obtained for *T5*, while no differences were observed for *T3* (Table 1). With regard to early defoliation, our results seem to confirm what has been found on other cultivars such as Sangiovese (Intrieri *et al.*, 2008), Barbera and Croatina (Bavaresco *et al.*, 2008), and Lambrusco Salamino (Poni *et al.*, 2009), that is, an increase in soluble solids compared with the untreated control (Table 1).

As for pH, increases were observed for *D3* and *D5* as compared to control. Our results seem similar to those obtained by Valdes *et al.* (2009) on Tempranillo. A similar response was observed for both *T3* and *T5*, while, similar to what has been found by Poni *et al.* (2006) on Trebbiano, no appreciable differences were observed for *DP*. Must TA ranged from 8.3 to 8.9 g/L in all treatments and was unaffected by *DP*, as has been found by several authors

(Poni *et al.*, 2006; Intrieri *et al.*, 2008; Tardaguila *et al.*, 2008), while a tendency towards higher TA for cluster thinning/cutting treatments was registered (data not reported).

3. Nutritional quality: antioxidant capacity, polyphenol and anthocyanin concentration

The effects of the various treatments on the nutritional quality of grapes (skins and flesh) are reported in Figure 1. Antioxidant activity in skin extracts was higher in all the samples subjected to canopy management techniques (Figure 1A). From the results of antioxidant determinations (antioxidant activity and phenol content), it emerges that the assays used had good repeatability, showing a coefficient of variation (CV) of < 3 % and < 5 %, respectively, while the method used for anthocyanin analysis showed a CV < 6 %. The antioxidant effectiveness of skin extracts increased over time, reaching a higher level in all the treatments at harvest as compared to control. The treatment that obtained the best grape nutritional quality in terms of skin antioxidant capacity (highest antioxidant capacity values) was *DP*. Cluster thinning increased the concentrations of cyanidin-3-glucoside, peonidin-3-glucoside, and, to a lesser extent, petunidin-3-glucoside, while the concentrations of malvidin-3-glucoside and acylated anthocyanins were unaffected by cluster thinning (data not reported). Hunter *et al.* (1991) reported the effect of partial defoliation (33 % and 66 %) from different developmental stages of Cabernet Sauvignon on grape skin colour, sugar concentration and wine quality, demonstrating that the anthocyanin content tends to be higher following partial defoliation and tended to increase when a later defoliation was carried out. The results concerning total anthocyanin concentration showed a negligible effect of early defoliation on anthocyanin biosynthesis, especially at harvest time, reaching concentrations similar to the control (Figure 1B). While only a minimal effect of early

Table 1 - Sugar content (soluble solids) and pH measured on the musts and total phenol content and antioxidant activity measured on the wines obtained from six grapevine canopy management treatments (data averaged over 2007). astringency intensity ranges from 1 (low intensity) to 5 (high intensity).

Treatment*	Sugars (°Brix)	pH	Total phenols	Lyphophilic antioxidant activity
			(mg of gallic acid /100 mL)	(micro moles of Trolox/liter)
C	22.1b	3.42b	102.6b	18.7a
DP	23.2a	3.45b	106.3a	17.6a
D3	23.9a	3.48a	97.0b	31.7b
D5	23.7a	3.66a	123.6a	20.0b
T3	22.6b	3.56a	71.6b	35.7b
T5	23.1a	3.69a	100.1b	30.8b

C = control; DP = early defoliation; D3 = cluster thinning 30 %; D5 = cluster thinning 50 %; T3 = cluster cutting 30 %; T5 = cluster cutting 50 %. Analysis of variance (ANOVA): means within columns designated by different letters are significantly different by the Fisher's test at $p \leq 0.05$; means within columns designated by the same letter are not significantly different.

Table 2 - Sensory evaluation of the wines obtained from six grapevine canopy management treatments (data averaged over 2007).

Treatment*	Vedel parameters				Total	Astringency intensity
	Visual	Olfactory	Gustatory	Harmony		
C	6.3b	8.5b	20.7a	7.7b	43.2	3.0b
DP	5.8b	14.5a	27.2a	15.4a	62.9	1.8c
D3	3.8b	9.8b	10.8b	6.7b	31.2	3.5b
D5	5.3b	10.2b	15.5b	8.7b	39.7	5.0a
T3	10.7a	15.3a	30.8a	20.2a	77.0	3.7b
T5	7.3b	16.3a	21.3a	14.3a	59.3	2.0c

*C = control; DP = early defoliation; D3 = cluster thinning 30 %; D5 = cluster thinning 50 %; T3 = cluster cutting 30 %; T5 = cluster cutting 50 %.

Analysis of variance (ANOVA): means within columns designated by different letters are significantly different by the Fisher's test at $p \leq 0.05$; means within columns designated by the same letter are not significantly different.

The score of the Vedel parameters is inversely proportional to the quality of the parameter evaluated; by contrast, the scale for astringency intensity ranges from 1 (low intensity) to 5 (high intensity).

defoliation was registered at harvest time where total anthocyanins reached 11 mg/100 g of skins (8th September), the other treatments obtained an improvement in anthocyanin concentration at every harvest.

Skin antioxidant activity expressed as mmol Trolox/100 g of fresh weight ranged from 0.4 to 1.65 according to Duda-Chodak and Tarko (2007). The antioxidant activity of different fruit parts (skin and pulp) was evaluated. In the case of pulp antioxidant activity, DP is the only treatment that showed lower values with respect to the control on two dates 18th September and 4th October (harvest time), whereas all the other treated samples had an antioxidant activity higher than control (Figure 1C). Pulp antioxidant activity was on average ten times lower than that of skins. Grape skins are known to have a higher phenolic concentration than pulp, especially in red grape cultivars, where large amounts of anthocyanins are present, hence contributing to the redness of the skin. Falchi *et al.* (2006) reported that the antioxidant activities of skin and pulp measured with DPPH (2,2-diphenyl-1-picryl-hydrazyl-hydrate) and EPR (electron paramagnetic resonance) methods were very different, finding that skin extracts did not show OH scavenging activity (EPR method) with respect to pulp; in contrast they reported higher scavenging action against DPPH for the skin extracts compared to that of pulp. Our results also confirm this: radical scavenger action against ABTS⁺ was much higher in the skin than in the pulp. Except for the pulp antioxidant activity of DP, our data showed the positive effect of canopy management on the nutritional composition of the grapes. This effect was particularly clear in the case of pulp antioxidant activity, which was more elevated in D3, D5, T3 and T5 than in the control,

especially on the last two sampling dates. Finally, with regard to pulp phenols, the pruning techniques yielded positive results compared with the control treatment (Figure 1D).

We analyzed the total phenol content and antioxidant activity of the wines (Table 1). Antioxidant activity was determined with a spectrophotometric assay as described by Re *et al.* (1999). Due to practical advantages such as assay time and use of automation, the ABTS⁺ scavenging assay is currently widely used to determine the free radical scavenging activity of wines and foods. The analyses carried out on the wine showed the considerable contribution of canopy management techniques to wine composition, with increased antioxidant activity in all treatments except DP and D5 (Table 1).

These data are seemingly in contrast with total phenol concentration, for which we observed few differences between treatments. Total phenol concentrations showed only a slight increasing trend in cluster thinning (50 %) and partial defoliation. This contrast between antioxidant activities and total phenol content was probably attributable to the fact that the radical scavenger activity was due to the action of numerous metabolites with radical scavenger power that are not detected with the Folin-Ciocalteu assay. In accordance with Prajitna *et al.* (2007), our results reported that canopy management improves the nutritional quality of wines, increasing the antioxidant capacity and yielding potential health benefits.

4. Sensory analysis of the wines

Table 2 shows the wine tasting scores for visual, olfactory and gustatory aspects as evaluated by the Vedel

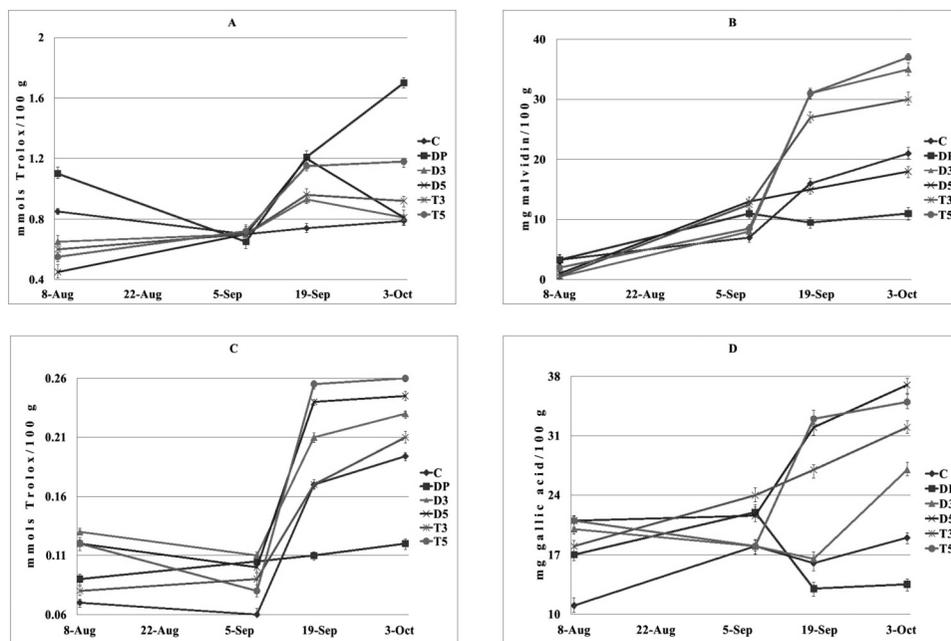


Figure 1 - Antioxidant activity in the skins (A); in the pulp (B); phenol content in the pulp (C); and anthocyanin content in the skins (D) measured on berries from six grapevine canopy management treatments (data averaged over 2007). C = control, DP = early defoliation, D3 = cluster thinning 30 %, D5 = cluster thinning 50 %, T3 = cluster cutting 30 %, T5 = cluster cutting 50 %; error bars indicate the standard error of the mean.

Chart. The total score (i. e., the sum of the various variables) was also considered. There were few colour differences between treatments, with the exception of T3, which had much less colour than the other wines. This corresponded to the total phenol content, for which T3 had the lowest value (71.6 mg gallic acid/100 mL; see Table 1). The other treatments (D3, D5, T5 and DP) did not differ from the control. In terms of aroma, T3, T5 and DP were different from C, D3, and D5. Treatments T3 and T5 clearly displayed an herbaceous character. Treatment DP, also displayed herbaceous traits and hints of astringency. The best aroma was found in the control and the cluster-thinned treatments (D3 and D5).

Considerable differences emerged between the wines in terms of retronasal aroma, mouthfeel, and taste: D3 and D5 were full bodied wines with elevated concentration of ripe tannins and a fruity aroma, which differed from all the other treatments. In this case, the high tannin concentration facilitates the production of vintage wines. Control and T5 showed a medium structure, good balance and a trace of fruitiness. These wines were pleasing and could be sold as young wines, with slightly astringent tannins and fruity flavours. The poorest, most unbalanced wine was T3, which had low tannin intensity, high acidity and an herbaceous character. The astringency results in the wine tasting (Table 2) allowed the treatments to be classified into three statistically different groups: the best structure and concentration of tannins was found in D5

(class a), followed by D3, T3 and C (class b), and then DP and T5, which proved to be the poorest in terms of tannins/astringency (class c).

The evaluation of harmony and global aspects also classified the treatments into three groups. As for harmony, the most harmonious were D3, D5 and C, followed by T5 and DP, and then T3. The poorest quality in terms of taste was T3. Finally, according to the total points scored, the best quality was associated with the cluster thinning treatments (D3 and D5) and the control, which were classified as “very good” (from 31.2 to 43.2 points), followed by T5 and DP, which were classified as “good” (from 59.3 to 62.9), and then T3, which was classified as “acceptable” (77.0).

CONCLUSIONS

This work confirmed the findings of many studies on other cultivars concerning the effect of canopy management techniques on both yield reduction and sugar increase in grape berries. On a practical basis, the tested techniques would appear advisable in many contexts in which yield control is needed and/or the composition of the musts has to be modified. Canopy management techniques produced a general increase in antioxidant activity in both the pulp and skins. This increase was associated with an increase in phenols (as compared to the untreated control) and was greatly favoured by the

cluster thinning treatment. With regard to the sensory evaluation of wines, the cluster thinning treatments gave the best results. These results would appear relevant to the consumer's interest, which is currently focused on the health benefits of moderate daily consumption of red wine. Considering the interactive complexity between climate, soil, training system, etc. on the one hand and the tested techniques influencing the diverse quality response on the other, we suggest an investigation of their effect, both individually and in any combination, for different areas of cultivation relative to oenological objectives. Nonetheless, in many climatic contexts where an improvement in the sensory quality of the wines is needed, the technique of cluster thinning could provide an appropriate solution to meet the viticulturist's expectations.

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