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Restoration of an old vineyard by replanting of missing vines: effects on grape production and wine quality

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Summary. – The viticultural and oenological characteristics of old and young Sangiovese vines were compared during a study set up by the Department of Agriculture, Food Environment (DAFE) in collaboration with an estate located at Cinigiano (GR), Italy, during two different vintages. Wines from each thesis were assessed for quality parameters and compared. The results show that the restoration of the vineyard, implemented by replacement of the missing vines, resulted in a quantitative and qualitative improvement over a decade. Indeed, the replanted vines were less vigorous and produced bunches of smaller size and with smaller grapes, which were characterized by a good phenolic endowment, especially for the anthocyanin component, which was also maintained in the wines.

Introduction. – Theoretically grapevine is a secular plant but, as wine quality is strictly linked to the growth and the fructification of grapevines (Blouin and Guimberteau, 2000; Conde *et al.,* 2007), when the vine is included in the analysis of the productive and economic purpose of the vineyard system, a specific technical lifetime should be defined (Morando *et al.,* 2006).

As widely reported in the literature (Eynard and Dalmasso, 1990; Fregoni, 2013) the biological cycle of a wine grape vineyard is characterized by an initial unproductive growth phase, lasting about 3 years, followed by some years with growing productivity. Thereafter, the adult vine reaches a productivity which remains constant for a period of 20-30

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years, followed by a descending phase which coincides with the old age of the vineyard. During this last part of the vineyard biological cycle, vines start to produce smaller crops and average yields decrease, leading to more concentrated, intense wines (Robinson, 2006). The vegetative and productive equilibrium (low yields) often observed in old vines constitutes one of the main factors that can explain the resulting quality (Zufferey and Maigre, 2008). Indeed, old vines are generally able to store a higher content of metabolites such as anthocyanins, flavones and flavonoids in the grape fruits, enabling the possibility to obtain a wine with a very interesting nutritional and organoleptic profile (Zufferey and Maigre, 2008).

Vineyard practices are primarily directed towards obtaining the maximum yield of a desired quality (Jackson, 2008), and in this context a full stand of vigorous, even-sized vines is essential to the economical, maximum production of the vineyard (Champagnol, 1984). Therefore, as a function of the vineyard conditions, it could be necessary to perform a vineyard "restoration". Actually, the operations linked to the restoration of an old vineyard need a lot of work and economical resources. Thus, the choice to restore an old vineyard instead of its uprooting is justified only by the quality degree of the produced grapes, the phytosanitary conditions of the grapevines, the suitability of the vineyard to mechanization, etc. (Morando *et al.,* 2006).

In this context the implementation of a series of interventions on soil, plants, trellis system, shoot density, cultural practices, and so on could be designed to preserve as long as possible an old vineyard affected by a vegetative and productive decay. Then, a careful cultural practice, together with a focused green management, will be necessary in order to enable the wished vegetative response of the vineyard, and to allow the aimed expression in terms of grape's characteristics and desired wine quality (Scalabrelli, 2009).

Moreover, since countless factors such as incorrect use of mechanical tools, bad weather conditions, vine diseases and attacks of parasites can lead to the death of some vines (Andreini *et al.,* 2014), the periodical replacement of the missing plants becomes of primary importance in order to maintain the maximum production of the whole vineyard.

There is a general recognition of an optimum vigour of shoots associated with the best combination of quantity and quality of production (Zufferey and Maigre, 2008), but the specific parameters associated to an "optimum vigour" are difficult to be defined and vary according to grape variety. Generally speaking, an excess of shoot vigour is detrimental, particularly if it occurs on mature vines trained to a restrictive trellis system. In these conditions, the vines tend to have dense canopies with a high degree of within-canopy shading. Therefore, control of excess vigour is desirable because it should not only lead to a more open canopy (with important indirect consequences for yield and fruit composition), but it is also important for producing a balanced vine (Dry and Loveys, 1998). Furthermore, it is well known (Champagnol, 1984; Eynard and Dalmasso, 1990; Fregoni, 2013) that also the planting density, in relation to the type of soil, rootstock and grape variety, has a remarkable effect on the final quality of the wine.

In this context, the Department of Agriculture Food Environment (DAFE) of the University of Pisa developed a research project at an experimental old vineyard, in collaboration with the "Azienda Agricola Salustri" located at Cinigiano (GR), Italy. The experimental old vineyard was restored by replacing the missing vines. After an equilibration time, lasting almost ten years from the replacement, the old vines (41-42 years) were compared with the young ones (11-12 years) by monitoring the quality of the grapes during ripening as well as the chemical quality of the wines produced with the same winemaking process applied to the differently aged vines.

Materials and Methods. – *Vineyard site, grapes and experimental design*. The experimental plot at Cinigiano (GR), Italy, is located at the "Azienda Agricola Salustri" farm in the *Montecucco* DOCG zone. The plot object of the restoration is about 1 ha, and it is constituted by *Vitis vinifera* cv. Sangiovese trained to a single cordon and spur-pruned (in-row vine spacing 1.5 m; between-row spacing 2.0 m), with an available soil space for each vine of 4.5 m^3. In order to replace the missing vines, which made up to about 50% of the whole vineyard, and to increase the planting density, new plants were planted in, both to restore the empty spaces and to reduce the in-row vine spacing from 1.5 to 0.75 m. At the time of the experimentation, the vine composition of the lot analysed (10 adjacent rows) at the sampling time was 45% old plants (41 years from the implantation) and 55% young plants (11 years from the implantation).

Winemaking. – The grapes coming from the old and young vines, both characterised by regular phytosanitary conditions, were hand-picked, added with 5 g/hL of SO_2 and separately processed at the DAFE experimental winery in a classic red microvinification, as reported in a previous paper (Venturi *et al.*, 2015). At the end of the maceration, the wines were drained off and after 15 days they were racked off from the lees. After three rackings, 5 g/hL of SO_2 were added to the wines.

Climatic conditions during ripening. – During the experimentation, the climatic conditions observed in the two vintages were very different. A higher rainfall characterized vintage A both in winter and in spring, and during the summer the temperatures were in line with the seasonal average values. On the contrary, during year B an alternation of temperature values higher (March and April) and lower (May and June) than the seasonal average ones was observed.

Plant characterization. – Morphological and phenological determinations useful for the characterization of vines and grapes were run at the DAFE – Section of Viticulture. Length (cm), weight (kg) and calibre diameter (mm) were determined on the shoots present on the fourth spur from the beginning of the cordons; the count of nodes and internodes (nodes/shoot length) was made as well. For each monitored grapevine all bunches were counted. In particular, one bunch for each grapevine was weighted, and its stalk and berries were measured and characterized in order to evaluate the weight, volume and percentage of grape components (grape-seeds, stalk, skin and pulp).

Chemical determinations. – All chemical determinations were run at the DAFE – Section of Food Technology. The sugar content of grapes and must concentrations of wines were determined using specific commercial enzymatic kits (Venturi *et al.*, 2013; Zinnai *et al.*, 2013a). Total titratable acidity, as well as pH, volatile acidity and formol index of musts and wines were systematically measured at harvest following the methods reported in previous papers (Zinnai *et al.*, 2011, 2013b; Venturi *et al.,* 2016a, b).

Statistical analysis. – To evaluate the statistical significance of the experimental data, for the same sample all measurements were repeated in triplicate. One Way Completely Randomized ANOVA (CoStat, Cohort 6 software) evaluated the reliability of data sets (4 treatments for three-repeated analysis). Tukey's HSD multiple mean comparison test ($P<0.05$) was used to state the differences among variables.

Results. – *Vegetative and yield performances of vines*. – The main parameters important for the definition of the vigour of the vines characterized by different ages (young and old) and during the two different vintages (A and B) were evaluated. As reported in Table 1, the grape

TABLE 1. – *Vegetative and yield performances of vines of different ages (old and young) during two consecutive vintages (A and B).*

	Old vines Vintage A	**Young vines Vintage A**	**Old vines Vintage B**	**Young vines Vintage B**
Shoot length (cm)	212.3[a]	187.0[b]	191.3[b]	176.3[b]
Shoot diameter (mm)	8.1[a]	6.7[b]	7.9[a]	6.5[b]
Shoot weight (g)	115.0[a]	71.2[b]	102.4[ab]	66.0[b]
No. of nodes	29.1[a]	28.5[a]	27.2[a]	27.4[a]
Internodes length (cm)	7.5[a]	6.4[b]	7.0[ab]	6.5[b]
No. of secondary buds per shoot	2.0[a]	1.1[b]	1.8[a]	1.1[b]
Secondary bud length (cm)	39.6[a]	20.3[b]	36.8[a]	19.3[b]
No. of bunches per vine	3.5[a]	1.8[b]	3.4[a]	1.9[b]
Grapes weight/vine (g)	942.0[a]	412.1[b]	1096.1[a]	440.2[b]
Bunch weigh (g)	269.1[a]	217.0[b]	320.1[a]	244.3[b]
Stem weight (g)	9.4[a]	8.0[a]	11.1[a]	8.7[a]

In each row, values labelled with different superscript letters show statistically significant differences ($P<0.05$).

yield per vine produced by the old plants was significantly higher than that showed by the young ones, regardless the crop season. Because of the climatic conditions, this difference was more evident during vintage B. Furthermore, regardless the crop year, young plants were characterized by a reduced internodal length and a lower shoot weight than the old ones.

Carpological determination. – As reported in Table 2, the carpological determinations did not show any significant difference as a function of the age of the vines, while the main carpological parameters (i.e. berry weight and berry composition) were deeply influenced by the weather trend observed in the two crop seasons (vintages A and B).

Grape chemical composition. – Since the two vintages were characterized by very different climatic conditions, in order to better highlight the effects of the age of the vines on the grape compositions, the concentrations of the chemical components were not expressed as mass unit/volume unit but as mass unit/berry. As reported in Table 3, sugar and phenolic contents were higher in vintage B regardless of the age of the plant. The values of titratable acidity were higher in the old vines, regardless of the crop season.

TABLE 2. – *Carpological parameters of grapes produced by vines of different ages (old and young) during two consecutive vintages (A and B).*

	Old vines Vintage A	**Young vines Vintage A**	**Old vines Vintage B**	**Young vines Vintage B**
Berry weight (g)	1.90^{a}	1.80^{a}	2.20^{a}	2.00^{a}
Berry volume (cm^3)	1.68^{ab}	1.61^{b}	2.05^{a}	1.77^{ab}
Skin weight (g)	0.13^{a}	0.12^{a}	0.14^{a}	0.15^{a}
Grape seed weight (g)	0.09^{a}	0.09^{a}	0.09^{a}	0.09^{a}
Pulp weight (g)	1.70^{ab}	1.60^{b}	2.00^{a}	1.70^{ab}
Grapeseed number	2.20^{a}	2.50^{a}	2.30^{a}	2.60^{a}

In each row, values labelled with different superscript letters show statistically significant differences ($P<0.05$).

TABLE 3. – *Technological characteristics and phenolic composition of grapes produced by vines of different age (old and young) during two consecutive vintages (A and B).*

	Old vines Vintage A	**Young vines Vintage A**	**Old vines Vintage B**	**Young vines Vintage B**
Sugar content (g/berry)	0.37^{b}	0.37^{b}	0.42^{a}	0.40^{ab}
pH	3.7^{b}	3.8^{a}	3.4^{c}	3.4^{c}
Total titratable acidity (mg/berry tartaric acid)	7.3^{c}	5.9^{d}	11.5^{a}	10.0^{b}
Total phenols (mg/berry catechin)	7.4^{b}	7.8^{b}	14.0^{a}	13.2^{a}
Total anthocyanins (mg/berry malvin)	1.8^{b}	2.1^{b}	2.6^{ab}	3.2^{a}
Free anthocyanins (mg/berry malvin)	1.5^{b}	1.8^{b}	2.1^{ab}	2.6^{a}
Proanthocyanidin (mg/L catechin)	2.0^{b}	2.0^{b}	4.0^{a}	3.8^{a}

In each row, values labelled with different superscript letters show statistically significant differences ($P<0.05$).

Wine quality. – The characteristics of the wines reflected substantially what was observed on the grapes. As reported in Table 4, alcohol content, titratable acidity and pH were influenced by the crop season, while the effect of the vine age on these parameters was not significant. Furthermore, wines produced with the young vine grapes exhibited higher phenol contents in both the vintages (Fig. 1), and a similar trend

TABLE 4. – *Chemical composition of wines produced by vines of different age (old and young) during two consecutive vintages (A and B).*

	Old vines Vintage A	**Young vines Vintage A**	**Old vines Vintage B**	**Young vines Vintage B**
Alcohol content (% v/v)	10.6^{d}	11.2^{c}	12.7^{b}	13.2^{a}
pH	3.6^{a}	3.6^{a}	3.4^{b}	3.4^{b}
Total titratable acidity (g/L tartaric acid)	6.15^{c}	6.9^{b}	7.2^{ab}	7.5^{a}

In each row, values labelled with different superscript letters show statistically significant differences ($P<0.05$).

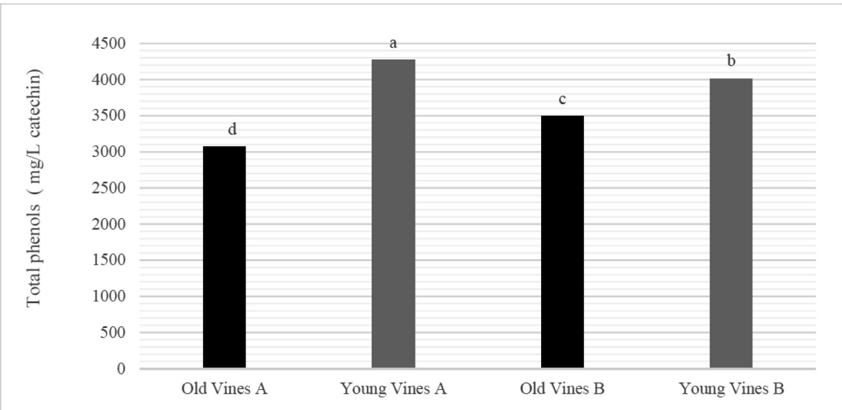

FIG. 1. – Total phenol content in wines obtained during two consecutive vintages (A and B) from grapes produced by old (black) and young (grey) vines. Values labelled with different superscript letters show statistically significant differences ($P<0.05$).

was observed analysing the data related to the total and free anthocyanin fractions (Fig. 2) and proanthocyanidins (Fig. 3). These differences could be justified by the different metabolism of the vines of different ages, as proved by the higher vigour of the older plants, which is one of the most likely mechanisms for decreasing phenolic content in grape (DOWNEY *et al*., 2006).

DISCUSSION. – Due to the strong influence of the available soil volume for the plant as well as the impact of the competitive environment, the young vines showed less vigour than the old ones, producing smaller shoots and bunches, which were characterized by smaller grapes but

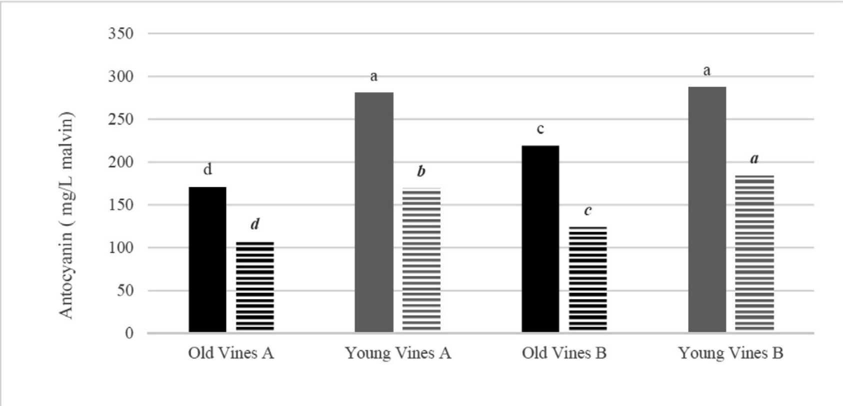

FIG. 2. – Total (plain colour) and free (striped) anthocyanins in wines obtained during two consecutive vintages (A and B) from grapes produced by old (black) and young (grey) vines. Values labelled with different superscript letters show statistically significant differences (P<0.05).

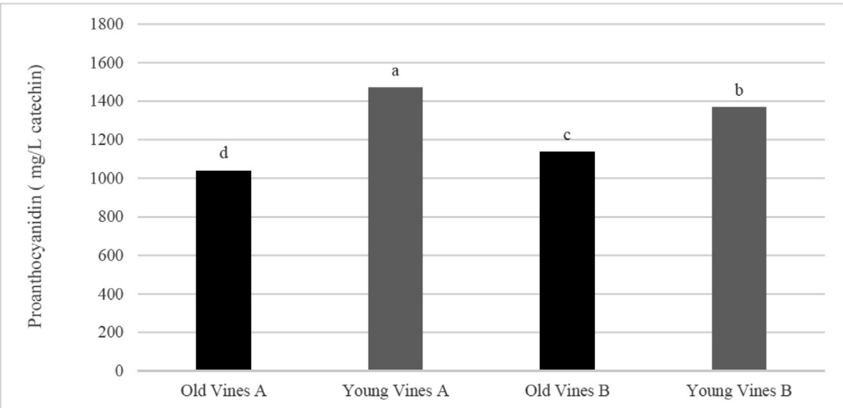

FIG. 3. – Proanthocyanidins in wines obtained during two consecutive vintages (A and B) from grapes produced by old (black) and young (grey) vines. Values labelled with different superscript letters show statistically significant differences (P<0.05).

with a similar technological maturity compared to the old vines. Interesting issues were also observed analysing the phenolic composition of grapes, in particular in the anthocyanin fraction, which was a little bit higher in the young grapes. These favourable compositional assessments would also characterize wines obtained from grapes produced by young vines, as verified by the comparison of the wines in the two vintages. Consequently, the replacement of the missing vines allowed the productivity of the vineyard to be maintained, and slightly increased the number of productive plants per hectare.

After twelve years from the planting, young vines presumably developed a sufficient root system which allowed them to ripen a moderate production load (< 1kg) with a composition comparable to that obtained with old vines that show a much higher productivity. The competitive environment is probably the cause of the young plants minor vigour, which is also reflected in the higher phenolic concentration and above all in the improved anthocyanin content, being both important compounds to obtain a high-quality Sangiovese wine.

The results show that the replacement of the missing vines in order to restore an old vineyard can result, over a decade, in a quantitative and qualitative improvement of its dynamic balance. Indeed, the replanted vines were less vigorous and produced bunches of smaller size and with smaller grapes, which were characterized by a good phenolic endowment, especially for the anthocyanin component, which was also found in the wines.

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