IT IS POSSIBLE TO PREDICT SANGIOVESE WINE QUALITY THROUGH A LIMITED NUMBER OF VARIABLES MEASURED ON THE VINES

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Abstract

Aims: The research work aimed at creating and testing a method to evaluate vine performance of Sangiovese (VPS), in particular, a method able to predict the potential oenological result through a limited number of variables measured on the vines.

Methods and results: A matching table was created on the basis of literature and the experience acquired over twenty years of research activity on Sangiovese vine and wine quality in Tuscany, which allowed the selection of eight viticultural parameters and three VPS classes. In order to validate the matching table, a specific experiment was conducted during the years 2002 and 2003 in 10 vineyards (selected from 7 farms) representative of the main soils and climates of the vine cultivation areas of the Province of Siena (Italy). The experimental results validated the proposed matching table through a non parametric statistical analysis. A multivariate regression analysis between wine sensory evaluation (score) and viticultural parameters significantly predicted wine quality even with only 4 grape parameters ($P < 0.05$).

Conclusion: It was possible to predict VPS by means of a matching table based upon eight simple viticultural parameters. The reliability of the wine quality prediction increased proportionally according to the number of viticultural parameters, but remained rather high ($R^2 = 0.606$) when taking into account only sugar content, sugar accumulation rate, mean berry weight, and extractable polyphenol index (EPI).

Significance and impact of the study: It is now possible to predict the quality of Sangiovese wines with a few selected grape parameters. Because of the wide variability in soil and climatic condition of the viticultural areas of the Province of Siena, where the method was developed, and the strong climatic contrast between the years when the method was validated, the use of both matching table and multiple regression is recommended for VPS prediction in Mediterranean environments.

Key words: soil, vine performance, grape, red wine, Tuscany

Résumé

Objectif: L'objectif de cette recherche est de créer et de tester une méthode pour évaluer la performance viticole du Sangiovese (PVS), une méthode permettant de prévoir le résultat œnologique potentiel, par l'utilisation de paramètres viticoles facilement mesurables.

Méthodes et résultats: Une table de comparaison a été créée sur la base de la littérature et de l'expérience acquise pendant vingt années d'activités de recherche sur le raisin et la qualité du vin Sangiovese en Toscane. Ceci a permis la sélection de paramètres viticoles pour évaluer la PVS. La table de comparaison a pris en considération huit paramètres viticoles. Un essai, pour valider la table de comparaison, a été mené en 2002 et 2003 dans10 vignobles sélectionnés (à partir de 7 fermes), représentatifs des principaux terroirs et des climats de vignobles de la Province de Sienne. Les résultats expérimentaux ont validé la table de comparaison proposée par une analyse statistique non paramétrique. Une régression linéaire multivariée entre l'évaluation sensorielle du vin (score) et les paramètres viticoles a prédit significativement la qualité du vin avec seulement quatre paramètres viticoles ($P < 0.05$).

Conclusion: Il a été possible de prévoir PVS par une table de comparaison basée sur huit paramètres viticoles simples. La fiabilité de la prédiction de la qualité du vin a varié proportionnellement en fonction du nombre des paramètres viticoles, mais est restée assez haute ($R^2 = 0.606$) en prenant en compte la teneur en sucres, le taux d'accumulation du sucre, le poids moyen des baies et l'indice des polyphénols extractibles.

Signification et impact de l'étude: Il est maintenant possible de prévoir la qualité du Sangiovese avec peu de paramètres viticoles. À cause de la large variabilité du sol et des conditions climatiques des zones viticoles de Province de Sienne, où la méthode a été développée, l'emploi de la table de comparaison, ainsi que de la régression multiple est recommandé pour évaluer la PVS dans bien d'autres environnements méditerranéens.

Mots-clés: sol, vigne performance, raisin, vin rouge, Toscane

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INTRODUCTION

The viticulture and oenology of Tuscany (central Italy) are the outcome of a secular tradition which shaped the region's landscape and deeply affected the socio-economic development of hilly agriculture. In Tuscany, Sangiovese is the main cultivar in the regional ampelographic outline: it is a major component in 33 denominations of origin (DOC and DOCG) and it occupies more than 60 % of the total vineyard surface. Its reputation is increasing, both in Italy and internationally (Fregoni, 2006). The DOC vineyards of Siena (Central Tuscany) comprise about 14,500 ha and produce some of the world's most renowned red wines, such as Brunello di Montalcino, Chianti and Chianti Classico, and Nobile di Montepulciano, all of which use Sangiovese as the main grape variety (Caldano and Rossi, 2008).

The territory of Siena has a prominent viticultural vocation. However, it is also well known that its high environmental variability has a huge influence over the viticultural and oenological results, mainly in the case of those varieties, such as Sangiovese, which have no strict genetic control over their vegetative and productive behaviours (Storchi *et al*., 1995). In fact, Sangiovese has a genotypic ability to limit the negative effects of water stress, reducing the transpiring leaf surface by means of permanent and irreversible adaptations of the oldest leaves (Palliotti *et al*., 2008). On account of that, the quality of Sangiovese wines is very dependent on the interaction between the climatical trend of the year and the soil characteristics.

The current target oenological model for Sangiovese wines, that is, what most winemakers try to obtain, is characterized by an alcohol content of about 12 °, a ruby red color with high color intensity and levels of total polyphenols (> 7.50 nm and > 2,000 mg L^{-1}, respectively), fine aromas of violet, blackberry and plum, and a well-balanced and persistent mouth feel.

Differences in yield and grape parameters are linked to viticultural management, climate and soil variations, and correspond to distinctive wine characteristics and quality. The term "vine performance of Sangiovese" (VPS) was used to define the vegetative and productive behaviour of this vine variety in a specific year and soil.

The evaluation of the oenological result in a particular year and plot is necessary if one wishes to assess the relationships between quality of Sangiovese wines and land characteristics. The evaluation can be obtained by means of a standardized oenological technique, such as small scale wine making. In this way it is possible to carry out a more reliable comparison of the wines, as the variability factors present in industrial wine making are controlled. It is also possible to perform a sensory evaluation of the wine made exclusively with the grapes of a particular plot (Gigliotti and Bucelli, 1990). However, the high specialization of small scale wine making limits its application to only experimental cellars. It is therefore necessary to use some parameters measured on vine and grape as predictors of potential wine quality. The parameters must be reliable, i. e. correlated to wine quality, sensitive, reproducible, and relatively easy to measure.

Lanyon *et al.* (2004) reported studies on grape component characteristics and wine quality. In particular, they found that the most valuable predictors were berry weight, berry sugar content, juice malate level, total anthocyanins and phenolics in berries or juice, and total glycosyl-glucose bound precursors. In Italy, the relationship between the vine performance of Sangiovese and its oenological result has been previously studied by Bertuccioli *et al.* (1998) in the Chianti Classico area. They found that some parameters indicating the quality of Sangiovese wines, such as alcoholic degree, pH, total acidity, ashes, total anthocyanins, and total phenols and their fractions, were correlated with the mean cluster weight, the number of buds per vine left at pruning, the onset of veraison and the total shoot length. More recently, Bertuccioli (2006) highlighted the relationship between the global quality (as score) of Sangiovese wines and their phenolic content. Since the latter parameter is correlated to extractable anthocyanins of grapes, their evaluation allows to predict the phenolic content of the corresponding wines and to estimate their global quality.

The aim of this work was to create and test a method to evaluate VPS on the basis of a limited number of easily measurable viticultural parameters.

MATERIALS AND METHODS

1. The matching table

The methodology followed the suggestions proposed by the Food and Agriculture Organization (FAO) to evaluate land suitability for different agricultural crops (FAO, 1976). The FAO system foresees the creation of a matching table to compare predictor and response variables. In the proposed matching table for Sangiovese, the selected measurable parameters of vine and grape (predictors) were classified according to their expected influence on the response variable, namely the quality of the Sangiovese wine. The selection and classification of the predictors made use of the experience obtained in many years of trials conducted in the Province of Siena, Montepulciano and the Chianti Classico area (Storchi *et al.*, 1995 and 2005; Costantini *et al.*, 1996 and 2010; Bucelli *et al.*, 1999 and 2006; Egger *et al.*, 1999).

The viticultural parameters selected for the achievement of a high quality Sangiovese wine were the following:

- Sugar accumulation rate from veraison to harvest in °Brix day^{-1}. The target wine should have values higher than 0.38 °Brix day^{-1}. Lower values indicate suboptimal nutrition during ripening, such an excess of water or nitrogen after veraison or close to harvest;

- Sugar content of must in °Brix. The optimum value is higher than 22 °Brix. Values lower than 20.0 °Brix are insufficient to obtain a high quality wine;

- Grape yield per vine in kg. The target value is between 1.0 and 2.5 kg, depending on vine density. The more this level is exceeded, the less positive is the oenological result, because of juice dilution. However, yields lower than 1 kg per vine are not economically compatible with the planting density in use in this area (about 3,500 vines per hectare);

- Mean cluster weight in g. The best wines are obtained when the value is in the range between 250 to 300 g: heavier clusters generally show excessive compactness and less coloured internal berries, because of shading;

- Mean berry weight in g. This is a very important parameter for the quality of red wines: heavier berries (bigger berries) reduce the surface to volume ratio to the detriment of polyphenolic content. The optimum value is less than 1.80 g, or between 1.80 and 2.30 g if the level of extractable polyphenols is higher than 1,600 mg kg^{-1};

- Must titratable acidity as tartaric acid g L^{-1}. The optimum value for a well organoleptically-balanced wine ranges from 5.50 to 7.50 g L^{-1};

- Extractable polyphenol index (EPI) from berry skin as (+)catechin mg kg^{-1}, in accordance with Di Stefano and Cravero methodology (1991). The reference value is higher than 1,600 mg kg^{-1}, indicating a high potential for well structured and full-bodied wines;

- Extractable anthocyanin index (EAI) from berry skin as (+)malvidine-3-glucoside mg kg^{-1}, in accordance with Di Stefano and Cravero methodology (1991). Grapes having values higher than 500 mg kg^{-1} generally produce well coloured wines.

The values of the selected parameters were then used to define three classes of VPS, corresponding to three levels of potential wine quality. The thresholds between classes were determined on the basis of the experience acquired during twenty years of research activity on Sangiovese vine and wine quality in Tuscany and the extensive literature on the subject, in particular, the following publications: Boselli *et al.* (2001) and Scalabrelli *et al.* (2001) studied the productive and vegetative parameters of Sangiovese grapevines during the 1993-1998 period in the Chianti Classico area (yield per vine; cluster and berry weight; sugar content at harvest; must total acidity); Bucelli (2001) evaluated the extractable anthocyanin and polyphenol index from the berry skin of 6 Sangiovese clones in the Province of Siena; Storchi *et al.* (2001) studied the carpometric and analytical characteristics of 11 Sangiovese biotypes and clones in the Chianti area; and Scalabrelli *et al.* (2006) evaluated the agronomic behaviour of Sangiovese vines in 11 vineyards of the Chianti Classico area for 3 years (1997-1999) considering yield per vine, cluster and berry weight, sugar content at harvest, must total acidity, and polyphenol and anthocyanin content of berries at harvest.

The matching table presenting the selected parameters classified into three classes of decreasing vine performance (VPS1, VPS2 and VPS3) is reported in table 1.

2. The experimental sites

The matching table was validated in a specific experiment conducted during the years 2002 and 2003 in 10 vineyards located in the Province of Siena, Italy. The selected vineyards were chosen as representative of the main soils and climates of the vine cultivation area after a survey of the whole province (Costantini *et al.*, 2006a and b).

In the vine cultivation areas of the Province of Siena, air temperature ranges from 13.5 to 14,8 °C, with a maximum in July and a minimum in January, and little yearly and monthly standard deviations of the long-term means. The long-term mean annual rainfall is between 730 and 850 mm, with high yearly and monthly standard deviations. The wetter months are usually October, November and December. The hilly territory, where vineyards are mostly concentrated, was formed in different geological eras and presents extremely variable characteristics. The low-lying areas consist of soils formed by the deposit of alluvial material with a deep rooting potential, dating from the Quaternary Period. Further uphill, on the Pliocene and Miocene marine sediments, the soils are mainly clayey and enriched by calcareous fossil material, but they are often rather thin due to severe water erosion. In the upper part of the territory, the soils are formed in older geological formations and they are usually moderately stony and sandy, rich in lime, and intermixed with wide areas of clayey and rocky soils. Paleosols are rather frequent on structural and fluvial terraces, in karst depressions but also on dissected surfaces and slopes (Costantini *et al.*, 2006b).

The 10 experimental vineyards were situated on 7 different farms (Table 2). The soils of the selected

Table 1 - Matching table of vine performance of Sangiovese (VPS) classes and predictors of potential wine quality.

Parameter		Class		
		VPS1	VPS2	VPS3
Daily sugar accumulation rate	°Brix day^{-1}	> 0.38	0.38-0.33	< 0.33
Yield per vine	kg	1.0- 2.5	2.6-4.0	> 4.0 or < 1.0
Mean cluster weigth (MCW)	g	< 250	250-350	> 350
Mean berry weight (MBW)	g	< 1.80 or > 1.80 if EPI > 1,600	1.80-2.30 or > 2.30 if EPI > 1,100	> 2.30
Sugar content at harvest	°Brix	> 22.0	22.0-20.0	< 20.0
Titratable acidity of must	g L^{-1}	5.50-7.00	5.00-5.49 7.01-7.50	< 5.00 or > 7.50
Extractable polyphenol index (EPI)	mg kg^{-1}	> 1,600	1,600-1,100	< 1,100
Extractable anthocyanin index (EAI)	mg kg^{-1}	> 500	500-300	< 300

vineyards were described in detail, sampled, analysed and classified according to the World Reference Base for Soil Resources (FAO-IUSS-ISRIC, 2006). All vineyards were not irrigated and had similar cultural conditions, such as age, vegetation and plant homogeneity: planting density of 3,300-3,600 vines per hectare; 420A rootstock; 11-12 buds per vine; spurred cordon pruning; and mechanically-tilled soil.

3. The experimental layout

Three plots, each made up of 10 Sangiovese vines, were chosen in each vineyard, which was equipped with a meteorological station to record the daily air temperature and rainfall. Soil water content at 0.1-0.3 m and 0.4-0.7 m (gravimetric method) and soil temperature at 0.5 m were measured every week. Gravimetric soil water content was converted into matrix tension (negative water potential) using the "Soil Water Characteristics" software (Saxton, 2009). Phenological stages (budbreak, flowering, veraison and ripening) were monitored and grapes were sampled and analysed at harvest as for grape yield per vine, cluster and berry weight, sugar content, pH and titratable acidity. The analysis of extractable phenols and anthocyanins of 100-berry homogeneous samples was carried out in accordance with the method of Di Stefano and Cravero (1991). A 80-kg grape sample was collected from each vineyard and processed using the same oenological technique as for small scale winemaking: crushing and destemming; addition of 50 mg L^{-1} SO_2 and 200 mg L^{-1} dry selected yeast; 8-day maceration with two pumping over the cap every day; and devatting and pressing. The wines were analysed (OIV, 2000) after the first racking with particular attention being paid to colour and structure parameters (Di Stefano *et al.*, 1997). About one year later, the wines were submitted to organoleptic testing by a panel of 14 assessors. An unstructured card was used, as proposed by Weiss (1981) for beer testing and further validated by Castino (1983) for wines. This card consists of a square with a diagonal line drawn from the bottom left (negative evaluation) to the upper right corner (positive evaluation). The panel is required to position the samples along the diagonal line on the basis of a comprehensive evaluation. Results were processed by the non-parametric Friedman's test (Conover, 1998)

The wines were classified into three groups of decreasing sensory evaluation (SE), as follows: SE1 (high) score > 75; SE2 (mean) score between 50 and 75; SE3 (low) score < 50. The VPS and the SE of Sangiovese in each of the 10 experimental vineyards, during the years 2002 and 2003, were evaluated according to the selected viticultural parameters and the score of the wine sensory evaluation. The statistical significance of the relationship between SE and VPS classes was checked using the chi-square (X^2) non parametric test. In addition, a multivariate linear regression between the sensory evaluation score and the selected vegetative and productive parameters of grapes was carried out to verify if wine quality could be predicted with less than 8 parameters and thus make the method easier to apply.

Table 2 - Geographical, pedological and geological description of the ten experimental vineyards.

Cultivation area	Vineyard code	Soil description	Soil classification (WRB; FAO, 2006)	Farm	Denomination of origin
Montalcino	P1	Gravelly silty clay loam, calcareous, with lime concentrations in depth, moderate hydraulic conductivity	Haplic Calcisols (Siltic)	Fattoria dei Barbi	Brunello di Montalcino
Montalcino	P2	Gravelly clay, calcareous, with lime concentrations in depth, moderate hydraulic conductivity	Haplic Calcisols (Clayic)	Tenuta Il Poggione	Brunello di Montalcino
Poggibonsi	P3	Clay loam over cobbly silt loam, calcareous, high hydraulic conductivity	Haplic Cambisols (Calcaric, Endoskeletic)	Fattoria Le Fonti	Chianti Classico
Poggibonsi	P4	Silt loam over very cobbly silt loam, calcareous, high hydraulic conductivity	Haplic Regosols (Skeletic)	Fattoria Le Fonti	Chianti Classico
Rapolano	P5	Very cobbly loam, not calcareous but base saturated, low hydraulic conductivity	Stagnic Cambisols (Skeletic)	Castello di Modanella	Chianti dei Colli Senesi
Murlo	P6	Silty clay, calcareous, low hydraulic conductivity	Stagnic Cambisols (Calcaric, Siltic)	Az. Agr. di Campriano	Chianti dei Colli Senesi
Murlo	P7	Silt loam, calcareous, low hydraulic conductivity	Stagnic Regosols (Calcaric Siltic)	Az. Agr. di Campriano	Chianti dei Colli Senesi
Cetona	P8	Silt clay loam, calcareous, low hydraulic conductivity	Stagnic Cambisols (Calcaric, Siltic)	Cantina sociale dell'Etruria	Chianti dei Colli Senesi
Cetona	P9	Silt loam, calcareous, moderate hydraulic conductivity	Haplic Cambisols (Calcaric, Siltic)	Cantina sociale dell'Etruria	Chianti dei Colli Senesi
Sovicille	P10	Silt clay loam, not calcareous but base saturated, moderate hydraulic conductivity	Haplic Luvisols (Rhodic, Profondic)	Tenuta di Trecciano	Chianti dei Colli Senesi

RESULTS AND DISCUSSION

1. Climate and pedoclimate during the studied years

The experiment was carried out in 2002 and 2003 in 10 vineyards located in the Province of Siena, Italy. The selected vineyards, annotated P1 to P10, are listed in table 2.

The two years of experimentation showed very different meteorological conditions. In the year 2002, the summer was moderately humid and cool, preventing the berries from reaching an optimal ripeness level. On the other hand, the summer of the year 2003 was very dry and hot, allowing the berries to reach high sugar content and harvest maturity about two weeks earlier than usually. Rainfall during budbreak-harvest time (April-September) showed the highest mean values in the P10 vineyard (Sovicille) in both vintages, while the lowest mean values in 2002 were recorded in Murlo (P7) and Cetona (P8 and P9) (Figure 1). In 2003, the lowest rainfall value was recorded in one of the Montalcino vineyards (P2).

Mean air temperature in the same period ranged from 25 to about 30 °C, with the highest values recorded in one of the Montalcino and Cetona vineyards (P2 and P8, respectively) (Figure 2). The soil temperature at 0.5 m ranged from 21 to 23 °C, with maxima in the vineyards of Montalcino (P2) and Poggibonsi (P3). The difference between air and soil temperature (D air-soil) at the beginning of the vegetation period (March-April) showed the highest value (11-12 °C) in one of the Cetona vineyards (P9) and the lowest values (about 5 °C) in the Chianti Classico (P3 and P4) and Cetona vineyards (P8).

The annual mean values of soil water tension during budbreak-harvest time almost doubled from 482 kPa in 2002 to 932 kPa in 2003 (Table 3). In the year 2002, only P2, P3, and P4 showed mean values at both depths higher than the 750 kPa threshold, which is considered as being an indicator of a severe summer stress. On the other hand, the very low water tensions in P6 and P10 indicated a probable excess of available water. In the year 2003, only P7 and P8 did not score above the 750 kPa threshold, and none of the plots seemed to have excess water. As a whole, the highest mean water tension values were recorded in Chianti Classico (P3 and P4) and Montalcino (P1 and P2), while the lowest values, that is, the highest water availability, were recorded in Murlo (P7), Cetona (P8) and Sovicille (P10).

2. Viticultural and oenological results

Both year and soil significantly influenced the viticultural result (Table 4). In particular, the soil strongly affected productive parameters, such as mean cluster weight, mean berry weight, grape yield per vine, some qualitative traits of the must (sugar content, pH and titratable acidity) and the extractable polyphenol index from berry skin.

Grape production and must quality differed significantly between the vineyards, especially in 2002, which was relatively more humid (Tables 5 and 6). In that year, P2 in Montalcino showed the significantly highest berry sugar content (°Brix), as well as sugar accumulation rate (°Brix day^{-1}) and extractable polyphenol index, while it had the lowest mean berry weight. Grape yield per vine, mean cluster weight and total acidity were also moderately low. In the same year, the grapes of P3 in Poggibonsi exhibited the highest significant extractable anthocyanin index. In 2003, the productive results were generally less variable among the plots. Still, P1 in Montalcino reached the highest level of extractable polyphenol index, with low yield per vine and mean cluster weight and good effective (pH) and total acidity of must.

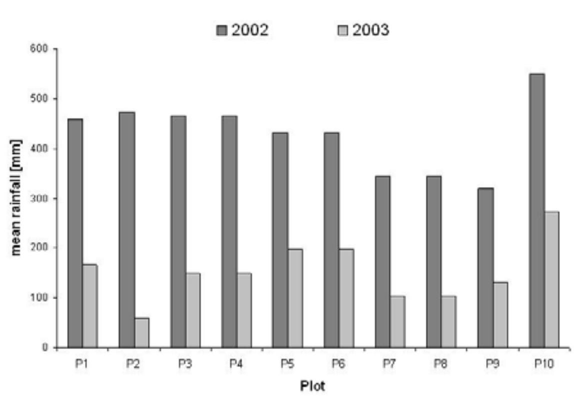

Figure 1. Mean rainfall during budbreak-harvest vegetative time in the years 2002 and 2003.

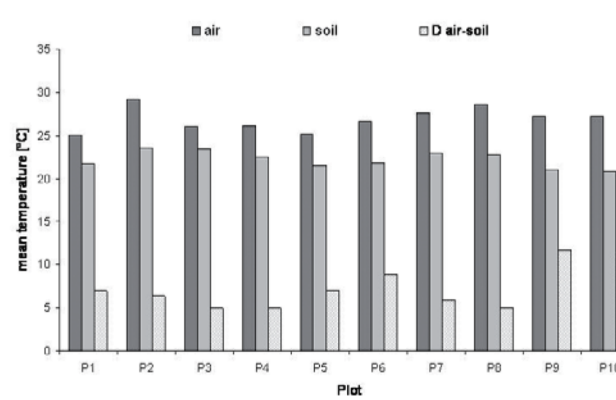

Figure 2. Mean values of air and soil temperature from April to September

D air-soil : difference between air and soil temperature at the beginning of the vegetative period (March-April) in the year 2003.

Table 3 - Soil water tension (kPa, negative water potential) measured from April to September in 2002-2003. Standard deviation in parentheses.

Vineyard code	Soil depth cm	2002	2003	Vineyard mean
P1	10-30	825(86.4)	1197(182.6)	
	40-70	455(43.9)	781(122.2)	
	mean	640	989	815
P2	10-30	1307(220.9)	1348(161.9)	
	40-70	265(32.7)	291(39.2)	
	mean	786	820	803
P3	10-30	603(121.7)	698(131.6)	
	40-70	918(111.5)	1289(220.2)	
	mean	761	994	878
P4	10-30	762(163.9)	1437(404.2)	
	40-70	nc	nc	
	mean	762	1437	1100
P5	10-30	360(52.2)	1047(75.2)	
	40-70	318(41.8)	881(101.3)	
	mean	339	964	652
P6	10-30	171(23.0)	1340(199.8)	
	40-70	174(19.4)	1083(144.5)	
	mean	173	1212	693
P7	10-30	364(60.5)	762(119.5)	
	40-70	277(44.6)	379(51.2)	
	mean	321	571	446
P8	10-30	391(52.9)	967(174.9)	
	40-70	227(32.5)	317(50.8)	
	mean	309	642	476
P9	10-30	539(102.8)	1316(47.3)	
	40-70	449(90.6)	487(112.4)	
	mean	494	902	698
P10	10-30	369(32.9)	1360(207.5)	
	40-70	101(4.7)	214(26.1)	
	mean	235	787	511
	annual mean	482	932	

nc : not calculated

As for the oenological results, there was more variability among the plots in 2002 than in 2003 (Table 7). A high alcoholic degree was measured for both years in Montalcino (P2), in both experimental fields of Chianti Classico (P3 and P4), and in one of two vineyards of Murlo (P7) and Cetona (P8). In 2002, Sociville (P10) and the wine of the second Cetona vineyard (P9) showed the lowest values and in 2003, the alcoholic content was high in all wines. The effective and total acidity of all wines was lower in the hot 2003 vintage. Colour intensity (DO_{420} + DO_{520}) and total anthocyanins and polyphenols showed a high degree of variability in both years. The Sangiovese wines obtained in Montalcino (P2) and Chianti Classico (P4) in the 2002 vintage had superior colour and phenolics than all the other experimental vineyards. Montalcino (P2), Rapolano (P5), Murlo (P6) and Cetona (P8) wines showed the highest levels of these parameters in 2003.

The organoleptic analyses of both vintages clearly showed the suitability of the experimental environments of Montalcino (P1 and P2) and Chianti Classico (P3 and P4) for the Sangiovese vine and its oenological result (Figure 3). Vineyard P4, in particular, showed the best qualitative potential by producing high quality wines with high sensory evaluation scores in both climatically contrasted years. The two Montalcino vineyards proved to be more subjected to climatic variability : P1, having cooler environmental conditions, gave the best quality results in 2003, which was a very hot and dry year, whereas P2, located in a hotter and drier pedoclimate, gave better results in 2002, which was a very moist summer. In the Chianti Colli Senesi experimental fields,

Table 4 - Analysis of variance : Year and soil effect on yield parameters and extractable polyphenol index from berries at harvest (years 2002 and 2003).

Parameter	Year	Soil	Interaction
Sugar content	***	***	***
pH	***	***	ns
Titratable acidity	***	***	***
Yield per vine	ns	***	nc
Mean berry weight	***	***	***
Cluster number per vine	ns	***	nc
Mean cluster weight	ns	***	nc
Extractable anthocyanin index	**	**	ns
Extractable polyphenol index	**	**	ns

*** Statistically significant differences P < 0.001 and ** P < 0.01 ; ns : not significant ; nc : not calculated

Table 5 - Grape production parameters at harvest. Mean values in 2002 and 2003.

Vineyard code	Sugar content °Brix		Sugar accumulation rate °Brix per day		Yield per vine kg		Mean cluster weight g		Mean berry weight g	
	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
P1	19.8E	24.5bc	0.37D	0.50BC	1.58DE	1.64d	234cd	166E	2.42B	1.86B
P2	23.9A	24.0c	0.50A	0.65A	1.64DE	2.72b	233cd	324A	1.53G	1.83BC
P3	22.3BC	23.1de	0.40BC	0.44E	2.44BC	2.61bc	265bc	304AB	2.22CD	2.09AB
P4	22.9B	23.9cd	0.42B	0.46DE	1.63DE	2.17c	172f	195CD	1.89F	1.78C
P5	20.2E	25.2ab	0.33EF	0.49CD	4.45A	2.31bc	225d	157E	2.08DE	1.42D
P6	21.2D	24.2c	0.39BC	0.65A	0.98E	1.15d	191ef	178DE	1.91EF	1.11E
P7	21.8CD	24.5bc	0.40BC	0.66A	1.77DE	1.64d	220de	218CD	2.28BC	1.96B
P8	21.9CD	25.7a	0.39C	0.52B	3.19B	3.29a	267b	279B	1.91EF	1.66CD
P9	19.3E	22.6e	0.35DE	0.46CD	5.04A	3.82a	321a	237C	2.03EF	1.67CD
P10	17.2F	22.5e	0.32 F	0.49C	2.12CD	2.61bc	253bc	291AB	2.79A	2.30A
Mean	21.1	24.0	0.39	0.53	2.48	2.39	238.1	234.9	2.11	1.77

In each column, values with different capital or small letters are significantly different for P < 0.01 and P < 0.05 respectively, according to HSD Tukey's test.

only some vineyards exhibited fairly good outcomes (P8-Cetona in 2002 and 2003 ; P5-Rapolano and P7-Murlo in 2003), while the others (P6, P9 and P10) received lower evaluation scores than those located in Montalcino and Chianti Classico. Therefore, in the 2002 vintage, the Sangiovese wine produced in the 10 experimental vineyards was classified SE1 in 2, SE2 in 2 and SE3 in 6 vineyards, while in the 2003 vintage it was classified SE1 in 2, SE2 in 5 and SE3 in 3 vineyards.

3. Validation of the matching table

The matching table presenting the target values and VPS classification can be seen in table 1. When considering the experimental data obtained during the two growing seasons, most vineyards (8) were classified as VPS2, 6 as VPS1 and 6 as VPS3 (Table 8). The contrasting climatic conditions also influenced these results. The very moist summer of 2002 did not allow all vineyards to reach a sufficient level of phenolic ripeness and sugar content in grapes. On top of that, the mean berry weight (MBW) was almost always higher than the target value. Only P2 exceeded the limit for VPS1-extractable polyphenol index of berry skin (1,600 mg kg^{-1}) and was below the VPS1-limit for MBW (1.80 g), whereas P2, P3 and P4 were the only ones to reach the VPS1 target level for sugar content (22 °Brix). On the other hand, in

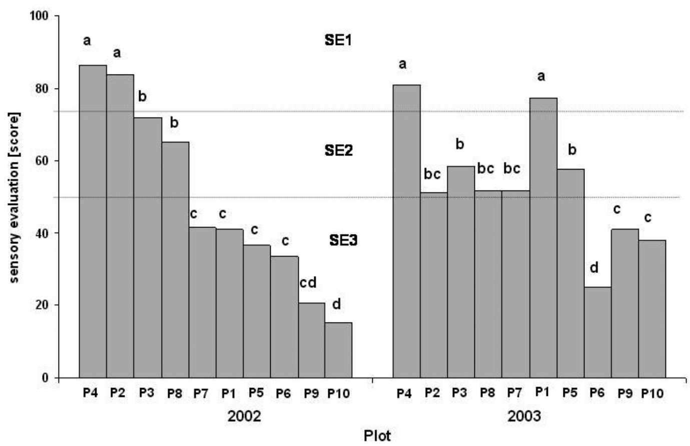

Figure 3 - Sensory evaluation of small scale wine making in the years 2002 and 2003.
In each year, columns with different letters are significantly different for P < 0.05, according to Friedman's test.

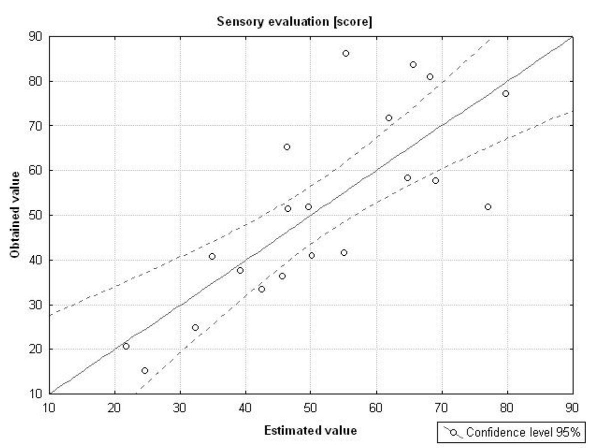

Figure 4 - Regression line between estimated and obtained values of sensory evaluation, and its confidence limits.

the hot and dry summer of 2003, all vineyards exceeded the VPS1 value for sugar content and sugar accumulation rate. In most vineyards the climatic trend caused a decrease of organic acids in vines (above all malic acid, data not shown), but the resulting values of must total acidity were higher than the set threshold for VPS1 (5.50 g L^{-1}), with the exception of P2. The hot summer also influenced phenolic ripeness : many grapes reached the VPS1 value for EAI and EPI.

The VPS classes were compared with the SE classes by means of the X^2 (Chi-square) Pearson non parametric test (data not shown). The calculated X^2 was very high ($X^2 = 21.833$) - higher than the tabular value (13.277) for $P < 0.01$ (Conover, 1998). So the independence hypothesis failed and we could conclude that the classes of sensory evaluation were significantly related to the classes of Sangiovese vine performance of the proposed matching table.

A multivariate regression analysis between sensory evaluation (score) and the vegetative and productive parameters of grapes significantly predicted wine quality ($P < 0.05$) even with only 4 grape parameters, that is sugar content in °Brix, sugar accumulation rate in °Brix day^{-1}, MBW and EPI :

$$Y = 8.689\ °Brix - 141.881\ °Brix\ d^{-1} + 0.042\ EPI + 16.546\ MBW - 170.646$$

$$R^2 = 0.606$$

where Y is the wine panel test score and R^2 is the coefficient of determination.

Nevertheless, the reliability of the wine quality prediction increased with the number of viticultural

Table 6 -Must parameters and skin polyphenols at harvest. Mean values in 2002 and 2003.

Vineyard code	pH		Total acidity g L^{-1}		Extractable anthocyanin index mg kg^{-1}		Extractable polyphenol index mg kg^{-1}	
	2002	2003	2002	2003	2002	2003	2002	2003
P1	3.14de	3.35c	7.35b	6.10a	258CD	568B	1,105D	1,869A
P2	3.27ab	3.59a	6.51c	5.02c	501AB	530CD	1,787A	1,695B
P3	3.27ab	3.52b	6.53c	5.55ab	574A	498D	1,415B	1,439D
P4	3.31a	3.40c	6.77bc	6.05a	446B	559BC	1,402B	1,612C
P5	3.17cd	3.37c	8.02a	5.50ab	531A	630A	1,278C	1,606C
P6	3.22bc	3.38c	6.43c	5.54ab	273CD	500D	1,265C	1,600C
P7	3.20cd	3.43c	6.26c	5.52ab	306C	620A	1,333B	1,650BC
P8	3.28ab	3.60a	6.58c	5.57ab	250CD	605A	1,210C	1,701B
P9	3.18cd	3.43c	7.12b	5.51ab	228D	498D	979E	1,493D
P10	3.10e	3.27d	8.01a	5.86a	464B	555BC	1,083D	1,100E
Mean	3.21	3.43	6.96	5.62	383.1	556.3	1285,7	1576,6

In each column, values with different capital or small letters are significantly different for $P < 0.01$ and $P < 0.05$ respectively, according to HSD Tukey's test.

parameters: it was $R^2 = 0.628$ with the former parameters plus EAI (total of 5 parameters), $R^2 = 0.656$ by further adding total acidity, $R^2 = 0.661$ by adding yield per vine, and $R^2 = 0.677$ by adding mean cluster weight.

Using the matching table with the first 4 selected parameters resulted in a very similar classification as the one previously obtained with 8 parameters: six vineyards fell into VPS1, ten into VPS2 and four into VPS3. Only one plot (P6, 2002), formerly classified as VPS3, was now classified as VPS2.

Solving the regression equation with the values of the first class of vine quality (SVP1), the sensory evaluation resulted in a 62.8 score, while it was 40.0 for the second class values. Figure 4 reports the regression line between estimated and obtained sensory evaluation values, and its confidence intervals. It must be noticed that the estimated values differed from the obtained ones mainly when the wine sensory evaluation was high, that is, when the wine quality was better. Although we can not exclude the influence of uncontrolled technological factors that might have varied during the small scale wine production, we can postulate that some of the qualifying notes considered by the panel, like, for instance, the intensity and finesse of the bouquet, were not correlated with the parameters of grape potential quality considered in the matching table. Moreover, we can also assume that when wine quality was medium or low, the influence of complex aromas on the panel evaluation decreased, and the result was more related to the basic parameters of grape potential.

CONCLUSION

The experimental results obtained during the years 2002 and 2003 in 10 vineyards located in representative cultivation areas of the Province of Siena validated the proposed matching table for the evaluation of the vine performance of Sangiovese. The reliability of the wine quality prediction varied according to the kind and number of viticultural parameters. It was possible to predict wine quality with only 4 grape parameters, making the method rather easy to be applied.

The productive components of the Sangiovese vine, as well as the quality of the wine, were closely related to the variability of soil parameters and meteorology of the year. In the more humid year, high water availability caused excessive fertility conditions, insufficient sugar content and phenolic ripeness of grapes and poor colour and phenolics in wines. In the hot and dry year, low water availability caused excessive stress conditions and lower total and effective acidity. Thus, as it is well known, a careful viticultural management is particularly important in these environments in order to regulate vine canopy to soil water availability.

The wide variability in soil and climate of the Province of Siena, where the method was validated, makes the use of both the suggested matching table for the Sangiovese performance assessment, and the multiple regression equation, potentially suitable for many other viticultural areas located in Mediterranean environments.

Table 7 - Analytical determinations of wines in 2002-2003.

Vine yard code	Alcohol % vol		pH		Total acidity g L^{-1}		Colour intensity nm		Hue		Total anthocyanins mg L^{-1}		Total polyphenols mg L^{-1}	
	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
P1	11.15	14.50	3.09	3.39	7.01	5.22	4.89	9.02	0.60	0.55	125	256	1,736	2,331
P2	13.95	14.15	3.39	3.52	6.56	5.02	10.38	6.15	0.63	0.77	295	279	3,197	2,799
P3	12.80	13.40	3.38	3.45	6.82	5.45	8.46	5.50	0.55	0.68	298	190	1,898	1,802
P4	13.00	13.95	3.32	3.48	6.75	5.25	9.63	7.51	0.60	0.63	253	251	1,924	2,140
P5	11.35	14.27	3.42	3.60	6.20	5.45	3.91	7.60	0.79	0.78	143	271	1,846	2,695
P6	11.91	13.46	3.31	3.51	6.37	5.28	4.27	9.95	0.70	0.63	176	327	1,690	2,667
P7	12.20	14.20	3.26	3.70	6.22	5.06	5.50	7.54	0.61	0.83	213	255	1,516	2,126
P8	12.85	14.05	3.46	3.67	6.30	5.40	5.52	8.09	0.82	0.74	163	259	1,854	3,015
P9	10.47	12.88	3.43	3.53	5.70	5.31	2.65	8.12	0.98	0.74	84	175	1,204	2,270
P10	9.58	12.71	3.10	3.44	7.42	5.78	3.64	5.26	0.60	0.67	122	137	1,118	1,742
Mean	11.93	13.76	3.32	3.53	6.54	5.32	5.89	7.47	0.69	0.70	187.2	240.0	1,798	2,359

Table 8 - Response evaluation (I, II, III) of viticultural and oenological parameters, according to the matching table and VPS classification of each vineyard in 2002 and 2003.

Parameter	P1		P2		P3		P4		P5		P6		P7		P8		P9		P10	
	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
Sugar accumulation rate	II	I	I	I	I	I	I	I	II	I	I	I	I	I	I	I	II	I	III	I
Yield per vine	I	I	I	II	I	II	I	I	III	I	III	I	I	I	II	II	III	II	I	II
Mean cluster weight	I	I	I	II	II	II	I	I	I	I	I	I	I	I	II	II	II	I	II	II
Mean berry weight	III	I	I	I	II	II	II	I	II	I	II	I	II	I	II	I	II	I	III	II
Sugar content	III	I	I	I	I	I	I	I	II	I	II	I	II	I	II	I	III	I	III	I
Total acidity of must	II	I	I	II	I	I	I	I	III	I	I	I	II	I	I	I	II	I	III	I
Extractable polyphenol index	II	I	I	I	II	II	II	I	II	I	II	I	II	I	II	I	III	II	III	II
Extractable anthocyanin index	III	I	I	I	I	I	II	I	I	I	III	I	II	I	II	I	III	II	II	I
Colour intensity of wine	III	I	I	II	I	II	I	I	III	I	III	I	II	I	II	I	III	I	III	III
Total anthocyanins of wine	III	I	I	I	I	II	I	I	III	I	II	I	II	I	I	I	III	II	III	III
Total polyphenols of wine	II	I	I	I	II	II	II	I	II	I	II	I	II	I	II	I	III	I	III	II
VPS	3	1	1	2	2	2	2	1	3	1	3	1	2	1	2	2	3	2	3	3

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