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Quality evaluation of grapes for mechanical harvest using vis NIR spectroscopy

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Abstract: Mechanical harvest of grapes is one of the operations that mostly influence the quality of the future wine. The shaking frequency of the harvesting machine is usually adjusted on the basis of the grape berry characteristics in order to limit grape juice production that is a potential cause of uncontrolled fermentations. These evaluations usually require time, personnel and laboratory analyses. The introduction of a vis NIR system to rapidly and reliably evaluate the berry properties in field before mechanical harvest could be a good alternative. The aim of this study was to evaluate the feasibility of applying vis NIR spectroscopy as a non-destructive technique on grapes cv. Syrah and Chardonnay to predict pedicel detachment force, pH and total soluble solids before mechanical harvest. The spectral acquisitions were performed using a portable vis NIR device (600-1000 nm). An Ordinary Least Square evaluation was applied to assess vis NIR prediction ability on grapes. The system gave excellent performance in predicting pH for both varieties (R^2=0.99), also confirmed by the indicators SECV/M and Bias/M respectively equal to 0.024 and 0.014 for cv. Syrah and 0.002 and -0.009 for Chardonnay. The vis NIR device showed satisfactory prediction ability even regarding total soluble solids (R^2=0.997 for Syrah and 0.9935 for Chardonnay) with SECV/M = 0.090, Bias/M = 0.071 for cv. Syrah and SECV/M = 0.00, Bias/M=–0.002 for Chardonnay. However, the results showed the low vis NIR ability to predict detachment force for Chardonnay grapes (R^2=0.85, SECV/M = 1.008; Bias/M = –0.834), and an acceptable one for Syrah grapes (R^2 = 0.87; SECV/M = 0.362; Bias/M = –0.109). Since detachment force has an enormous importance in grapes mechanical harvest, the possibility of applying vis NIR spectroscopy in field before harvest is very encouraging for cv. Syrah (red grapes) and needs to be improved for cv. Chardonnay (white grapes).

Keywords: detachment force, dynamometer, non-destructive analysis, Ordinary Least Square (OLS), wine quality

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1 Introduction

The consumer requires today products with increasingly high organoleptic and sensory quality. His implicit expectations about wine are represented by safety and hygiene, while the explicit expectations refer to organoleptic quality, nutritional value and stability of the product. We see today a growing interest in sustainable and high-quality production especially in the agro-food sector where the use of automated and precise monitoring analytical systems begins to spread (Cozzolino and Dambergs, 2010).

The physiological characteristics of grape berries in a vineyard may be considerably different (Torchio et al., 2010). At the base of a quality product, there is the need to find raw materials, grapes in our case, that have the right requirements. In this context it is important to measure sugar concentration in the must through refractometric indices, as well as determine total acidity and pH through volumetric titration using NaOH and selective electrodes. The traditional methods are destructive and require much time and materials. Therefore, the use of rapid and non-destructive techniques becomes particularly interesting, as they can replace the traditional methods especially if they reach high reliability.

In recent years, many researchers developed

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non-destructive techniques and instrumentations to increase the number of fruits to be monitored and the analyses that can be repeated on the sample fruit during ripening and storage, achieving real-time information (Costa et al., 2009). These instruments may help the sector to optimize the harvest time and thereby increase the final quality of wine.

Visible near-infrared spectroscopy (vis NIRs) (400-2500 nm) offers the possibility to screen and characterize many type of fruits ’on-line’, opening new objective of market segmentation and fruits valorization, both fresh and processed (Bureau et al., 2009). Vis NIR spectroscopy technique has been widely used for rapid and non-destructive analysis of chemical constituents such as starch content, soluble solids content, water content, pH or firmness and other physiological properties of fruits such as mandarin (Kawano et al., 1993; McGlone et al., 2003; Vallone et al., 2016), citrus fruit (Steuer et al., 2001; Miller and Zude-Sasse, 2004; Cayuela, 2008; and Zude et al., 2008), tomato (Slaughter et al., 1996), mango (Saranwong et al., 2004), kiwifruit (Osborne and Künnemeyer, 1999), apple (Lammertyn et al., 1998; Park et al., 2003; Guidetti et al., 2005; and Beghi et al., 2013), persimmon (Altieri et al., 2017).

In the wine sector it is extremely important to accurately and real-time know the grapes parameters that can influence the quality of the final product. Vis NIRs has found wide application in predicting grape qualities such as pH and soluble solids content (Baiano et al., 2012; Beghi et al., 2014; Cao et al., 2010; Menesatti, 2007; and Urraca et al., 2015), anthocyanin concentration (Larraìn et al., 2008; Fernandes et al., 2015), total phenol content (Piazzolla et al., 2013; Nogales-Bueno et al., 2014) to optimize the time of grapes harvest. In Lv et al. (2012) vis NIR was applied to identify the different degree of maturation of grapes during the harvest period. NIR spectral data were also used for quality control of white and red grapes during on-vine ripening to distinguish between different ripening stages, as a function of the berry position in the bunch and bunch orientation (González-Caballero et al., 2011; González-Caballero et al., 2012; Guidetti et al., 2010). In Ferrer-Gallego et al. (2013), taste (sourness), texture (astringency, tannic intensity, dryness and hardness), visual (colour) and olfactory (intensity and type of aroma) attributes were studied using NIRS technology to decide on the optimal harvest time.

By contrast, there are a few studies regarding berry texture. Beghi et al. (2014) used vis NIR spectroscopy to evaluate the withering of grapes for the production of passito wines through firmness determination. Ribera-Fonseca et al. (2016) tested a portable and friendly-use vis NIR instrument providing an Index of Absorbance Difference (IAD), calculated on the basis of two wavelengths (560 and 640 nm), in order to evaluate soluble solids, titratable acidity, firmness and anthocyanins in cv. Sangiovese grapes. An on-line implementation of vis NIR spectrometers in wineries at grapes arrival was performed in Porep et al. (2014, 2015) for a rapid and objective assessment of the composition of grapes in order to improve systems for payment and quality management.

There are no studies about the use of vis NIR spectroscopy for the evaluation of the berry detachment force from the pedicel. This is a discriminant parameter in the adjustment of the shakers of the mechanical harvesting machines, therefore very important for the effect on future wine quality. As is known, the lower the pedicel resistance to detachment, the lower the shaking frequency during mechanical harvest and, therefore, the must production that is generated during mechanical harvest because of the energetic action of the shakers against the bunches to allow the separation of the grape berries (Morris, 1998). Musts production has to be limited as it promotes the start of uncontrolled fermentations altering the quality of the future wine when combined with ambient temperatures above 30°C (Pocock and Waters, 1998).

In the hedgerow vineyards the frequency of the shakers is adjusted according to the forward speed of the machine, the bunches position, the vegetation and the grape variety in order to obtain high harvest efficiency and low must production (Clary et al., 1990). The must production, being equal the structural conditions of the plants, depends on the physico-mechanical characteristics of the berry including its breaking strength and pedicel detachment force.

The objective of this study was to evaluate the feasibility of applying vis NIR spectroscopy as a non-destructive technique on grapes cv. Syrah and Chardonnay to predict pedicel detachment force (DF), pH and total soluble solids (TSS) before mechanical harvest for high-quality wine production.

2 Materials and methods

2.1 Fruit materials

In 2016, Vitis vinifera L. cv. Chardonnay and Syrah grape samples were harvested from two vineyards of the farm “Tenute Principe di Corleone”, located in the province of Palermo (Sicily, South Italy) at 540 m above sea level. The vineyards, 10 years old and planted at 2.5 m×1 m, were grown in hedgerow system with conventional cultivation techniques; they were cordon pruned and the average yield per plant was about 2.5 kg.
In Italy cv. Chardonnay is grown in almost all regions, especially in Sicily, where it has found its natural habitat thanks to the climate and to the chemico-physical properties of the soils. Chardonnay is considered a vigorous variety with a moderate grape yield; its berry clusters are small, cylindrical and winged and can range from well-filled to compact (Kerridge and Antcliff, 1999). Syrah cultivar has elongated cylindrical bunches with visible and slightly woody stalk; the berries are oval shaped and have pruinose and low consistence skin, blue colored.

2.2 Sampling

Grape sampling was carried out weekly in the period from late July to early September, 2016, six times for Chardonnay and five for Syrah cultivar.

The variability of the samples was assured in this way in the period from late ripening to full maturity of the grapes (Bosco, 2010). Every time three bunches were randomly picked respectively at the top, middle and bottom of the plants with the aim of obtaining representative samples. The bunches were stored at 4°C in order to slow down the drying process and to inhibit the action of any microorganisms that could deteriorate the chemical-physical characteristics of the berries. In the same day, twenty berries were taken from each bunch through scissors, with the pedicel attached, for a total of sixty berries per time and per cultivar having on the whole 360 Chardonnay and 300 Syrah berries, according to Urraca et al. (2015) who identified the minimum threshold of 250 samples for the calibration set to obtain acceptable results in terms of accurate and stable predictions with a hand-held NIR spectrometer.

2.3 Portable vis NIR device

The spectral acquisitions were performed using a vis NIR system (model NCS001, Sacmi, Imola, Italy) that was operated in the wavelength range 600-1000 nm in transmittance mode. The system consisted of five elements (Figure 1): a lighting system, a power pack for lighting, a spectrophotometer, a PC for the user interface, which is responsible for data display and management parameters, and a fan to control the temperature. A control keyboard and a monitor completed the system. The measurements were acquired using a dedicated software (NCS software package, Sacmi, Imola, Italy). The system was based on the projection of an intense light beam with a near-infrared frequency band through the body of the product. The resultant light was collimated into a single narrow beam and analyzed to determine the parameters of interest. Two acquisitions were performed for each berry along the equator region on opposite sides. A 100 mm^2 Teflon disk was used as the optical reference standard for the system, since Teflon has low reflectance and its light-scattering characteristics were similar to those of the samples.

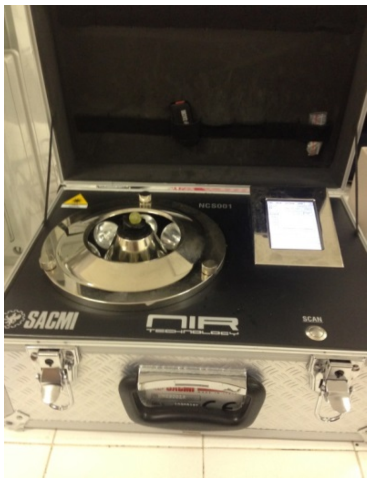

Figure 1 The vis NIR spectrophotometer (NCS001, Sacmi, Imola, Italy) with a Chardonnay berry sample during the tests

2.4 Physico-chemical analyses

2.4.1 Detachment force

Detachment Force is a mechanical parameter given by the berry detachment force from its pedicel. It is strongly influenced by withering (Letaief et al., 2008) and represents an important ripeness indicator, together with pH and sugar content. Berry detachment force measurements can be useful to adjust the frequency of the shakers in grape harvesting machines (Carrara et al., 2007). The mechanical tests to evaluate detachment force were performed using a mechanical dynamometer (DPS 5R, Imada, Northbrook, Ill.), connected to an electronic stand (MX2-500N-L, Imada) and a PC for data download. The pedicel separation was achieved with tweezers connected to the dynamometer (Figure 2). The test speed was set at 0.167 mm s^{-1} keeping it constant during the tests (Catania et al., 2014). Figure 3 shows an example of force-distance curve obtained using the dynamometer for Chardonnay and Syrah berries. The detachment force was identified as the peak of the curve.

Figure 2 Dynamometer IMADA, DPS 5R for berry detachment force measurements

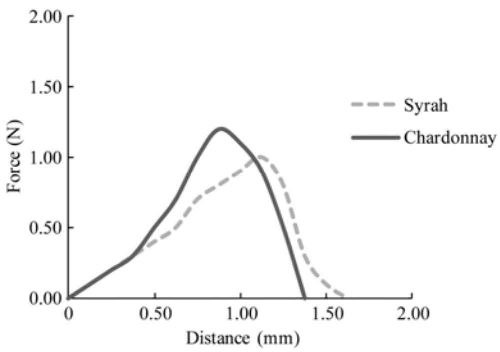

Figure 3 Example of force-distance curve during berry detachment test

2.4.2 pH values

pH provides indication on the future acidity of the wine and gives information about grapes ripeness. It depends on the type and concentration of the free acids; it usually varies between 2.8 and 3.8, even changing during ripening, winemaking and storage. pH is very important in winemaking; the color tone and brightness of red wines depend on it. pH values were measured using a portable pH meter (MM40 multimeter, Crison Instruments, Barcelona, Spain).

2.4.3 Total Soluble Solids

Grape sugars provide the most important indication on ripening; they are almost all hexoses (monosaccharides with six carbon atoms) such as glucose and fructose and minimally pentoses (monosaccharides with five carbon atoms) such as xylose and arabinose. The hexoses, if fermented by yeasts, are transformed into ethyl alcohol, water, carbon dioxide and other by-products. Sugar content in musts gives information about the potential alcohol content.

Total Soluble Solids were measured in °Brix using a portable refractometer (MR32ATC, Milwaukee Instruments, Rocky Mount, N.C.) after the spectrophotometer acquisitions of each berry and by directly squeezing the juice onto the refractometer, which was previously calibrated with distilled water.

2.5 Statistical analysis

An Ordinary Least Square (OLS) evaluation was applied to assess vis NIR prediction ability on grapes about DF, pH and TSS. OLS evaluation correlates the measured and the predicted values of the parameters. The estimated model is:

$$y_{ij} = \beta_j x_{ij} + \varepsilon_{ij} \tag{1}$$

where, y_{ij} and x_{ij} are respectively the i^{th} predicted and measured value of the parameter j; β is the regression coefficient and expresses how much a unit of the measured value corresponds to the predicted value.

The indicators R^2 (coefficient of determination), Rho (correlation coefficient), SEC (Standard Error of Calibration), SEC/M (ratio of the Standard Error of Calibration to the Mean) and Bias/M (ratio of distortion between observed and estimated value to the mean were furthermore adopted to evaluate the prediction ability of our vis NIR system.

R^2 is a measure of the mean vis NIR capability of explaining overall variability observed on the measured values. The linear Bravais-Pearson correlation coefficient Rho evaluates on average the concordance or discordance between predicted and observed values; SECV gives a measure of cross validation of vis NIR predicted values respect to measured values, being an average validation error measure. SECV/M was also introduced to make comparable the cross-validation measures for the three parameters considered, in this way removing the mean order of magnitude effect of an observed parameter on the measure of variability. For the same reason in this study it was decided to calculate Bias/M instead of Bias to compare the distortion size in the three parameters.

After estimating the relationship between predicted and observed values, the normal distribution of the residuals was evaluated for each parameter through observation of the histograms of standardized residuals. If residuals do not have a normal distribution the vis NIR would not be able to determine with accuracy the correct values of the parameters; in this case the vis NIR predictive model is not well specified probably because not adequately set up or because it adopts previsions algorithms that should be reviewed.

3 Results

3.1 Spectra plots

The mean spectra of the white (cv. Chardonnay) and red (cv. Syrah) berry samples in the 600-1000 nm range are reported in Figure 4. Red and white grapes mean spectra were quite similar as obtained in Nogales-Bueno et al. (2014) who applied hyperspectral imaging analysis to Zalema (white) and Tempranillo and Syrah (red) cultivars. The peak at 680 nm corresponds to the clorofill absorption peak (McGlone et al., 2002). The strong peak observed at about 840 nm can be related to sugars (Baiano et al., 2012).

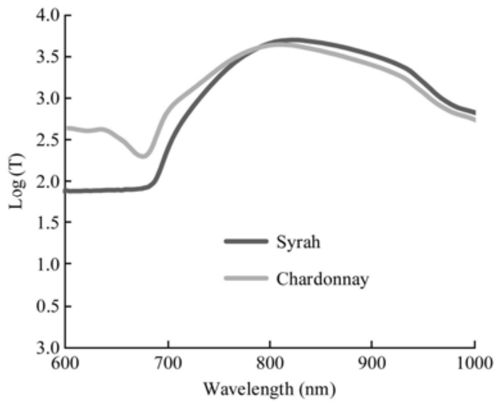

Figure 4 Mean spectra for berries of the two grape varieties in the 600-1000 nm range ($n = 360$ for cv. Chardonnay and $n = 300$ for cv. Syrah

3.2 vis NIR device prediction ability

The descriptive statistics for DF (Table 1) show the mean predicted detachment force to be higher than the measured one for both varieties, mainly for cv. Chardonnay, whereas pH mean predicted value was very close to pH mean measured value both for cv. Syrah and Chardonnay. TSS mean predicted value was lower than the measured one for both grapes varieties.

Table 1 Descriptive statistics of cross-validation on Syrah and Chardonnay berries

Variable	Syrah				Chardonnay			
	Mean	Std. dev.	Min	Max	Mean	Std. dev.	Min	Max
DF Measured	1.030	0.399	0.20	2.40	1.135	0.455	0.30	2.20
DF Predicted	1.157	0.158	0.77	1.59	2.082	0.186	1.42	2.55
pH Measured	3.742	0.105	3.52	4.00	3.781	0.091	3.55	3.93
pH Predicted	3.690	0.095	3.29	3.92	3.815	0.057	3.67	3.95
TSS Measured	27.135	1.287	24.50	31.00	22.500	1.635	19.00	26.00
TSS Predicted	25.338	0.894	22.64	27.84	20.039	1.341	16.43	22.74

Note: The number of samples for cross-validation was 85 and 50 respectively for cv. Syrah and cv. Chardonnay. Std.dev = standard deviation.

Table 2 shows the confidence intervals of β coefficients obtained through the OLS estimation of Equation (1) for both grapes varieties and the three parameters considered.

When β is equal to 1 it means that the system has an excellent prediction ability, considering that to each unit of an observed datum corresponds a predicted value equal to β. If the vis NIR device is able to predict the values of the parameters it was trained for, any deviation from the real value is due to random errors which should have a normal distribution.

Vis NIR instrument prediction quality is explained by the indicators reported in Table 3.

Table 2 Estimation of the correlation coefficients between predicted and measured values in the two grape varieties

	Syrah						Chardonnay					
	β	Std.Err.	t	P>t	[95% Conf.	Interval]	β	Std. Err.	t	P>t	[95% Conf.	Interval]
DF	0.987	0.041	23.90	0	0.905	1.069	1.581	0.094	16.880	0.000	1.393	1.769
pH	0.986	0.002	487.63	0	0.982	0.990	1.009	0.003	335.450	0.000	1.003	1.015
TSS	0.932	0.005	171.59	0	0.921	0.943	0.887	0.010	87.720	0.000	0.867	0.908

Table 3 Vis NIR prediction quality indicators for cv. Syrah and Chardonnay

Variable	Syrah					Chardonnay				
	R^2	Rho	SECV	SECV/M	Bias/M	R^2	Rho	SECV	SECV/M	Bias/M
DF	0.872	0.184	0.418	0.362	-0.109	0.8533	-0.062	1.144	1.008	-0.834
pH	0.999	0.756	0.087	0.024	0.014	0.9996	0.502	0.007	0.002	-0.009
TSS	0.997	0.182	2.290	0.090	0.071	0.9935	0.335	0.007	0.000	-0.002

3.2.1 Detachment Force

Detachment Force shows a scarce correlation between predicted and observed values for both varieties, although significant, with β equal to 0.987 for cv. Syrah and 1.581 for Chardonnay (Table 2). The confidence interval for Syrah grapes in 95% of the cases, varies between 0.905 and 1.069 and this means that vis NIR device could perform a 9% DF values underestimation or a 7% DF overestimation. For Chardonnay grapes, in 95% of the cases, the confidence interval varies between 1.393 and 1.769 and meaning that vis NIR device could perform a DF overestimation between 39% and 77%.

The results reported in Table 3 show the low vis NIR ability to predict DF for Chardonnay grapes (R^2=0.85) and SECV/M equal to 1.008, therefore not acceptable because greater than one. In addition, DF predicted mean value was higher than the observed (Table 1) (2.082 against 1.135) and bias/M was equal to –0.834 (Table 3). The results obtained for Syrah grapes were better than Chardonnay (R^2=0.87; SECV/M=0.362; bias/M=–0.109).

Confidence intervals for an individual forecast for both varieties are shown in Figure 5. The grey area represents the confidence interval, the dots are the observations, the blue line stands for the predicted values from the linear model (1). The orange line $y=x$ represents the case of exact correspondence between predicted and observed values. Confidence intervals were established considering the standard error of prediction. Figure 5 also shows the outliers. The practically overlapping between the blue and orange lines showed the perfect correspondence on average, between predicted and observed values for Syrah grapes. On the contrary, there was a very high distortion of the DF vis NIR predicted values from those observed for Chardonnay grapes.

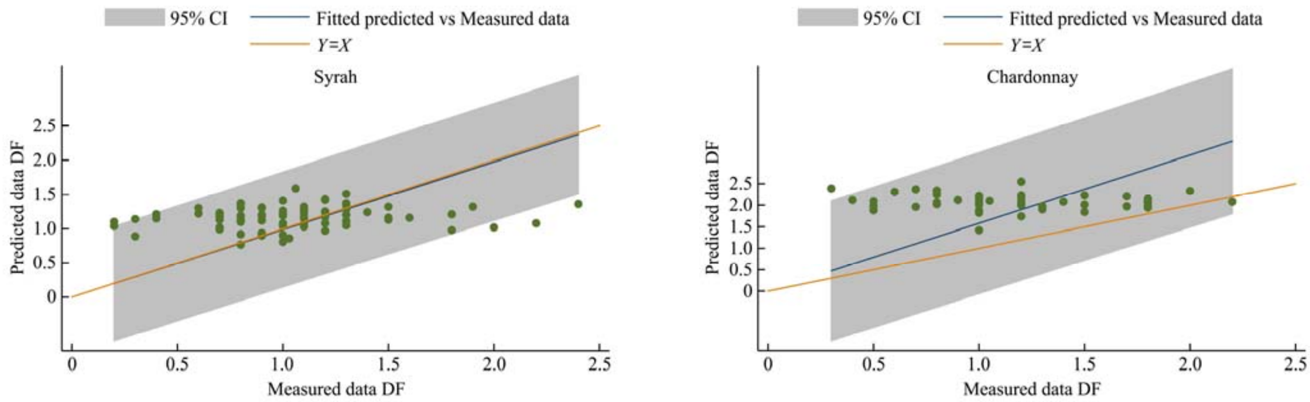

Figure 5 Detachment Force confidence intervals for an individual forecast

3.2.2 pH values

The confidence interval of pH predicted values highlighted the excellent prediction ability of the vis NIR system for both grapes varieties (Table 2). The pH prediction interval was much more restricted respect to DF, then subject to a lower prediction error.

In our study, the prediction ability of the vis NIR device was also confirmed by the indicators SECV/M and Bias/M respectively equal to 0.024 and 0.014 for cv. Syrah and 0.002 and –0.009 for cv. Chardonnay (Table 3). The vis NIR system underestimated, on average, the observed values for cv. Syrah (Figure 6, blue line under the orange one) whereas it overestimated them for cv. Chardonnay (blue line above the orange one).

3.2.3 Total Soluble Solids

The vis NIR system used in this study showed satisfactory prediction performance even regarding TSS. Almost all of the predicted values were located within the prediction intervals for both cultivars (Figure 7); the model adopted to evaluate the reliability of the predicted values led us to consider that in 95% of cases they were underestimated compared to the observed ones. This underestimation varied from 9% to 13% compared to the observed values for cv. Chardonnay (confidence interval 0.867-0.908, Table 2) and from 6% to 8% (confidence interval 0.921-0.943, Table 2) for cv. Syrah. The indicators of predictions quality were discordant, low correlation in view of high R^2 values and low SECV/M values both for Syrah and for Chardonnay. This could be explained by the vis NIR underestimation of all TSS values especially those higher; it reduced the predicted values variability this involving a covariance reduction between predicted and observed values. R^2 and SECV/M values gave an excellent vis NIR system prediction ability; if we consider the confidence intervals (Table 2) the acceptability of the result greatly depends on the level of accuracy we want to be given to the forecast. On the basis of these evaluations, we consider acceptable the predicted values when they are by about 10% lower than the real ones. The residues showed asymmetrical distribution due to the overestimation of many TSS values.

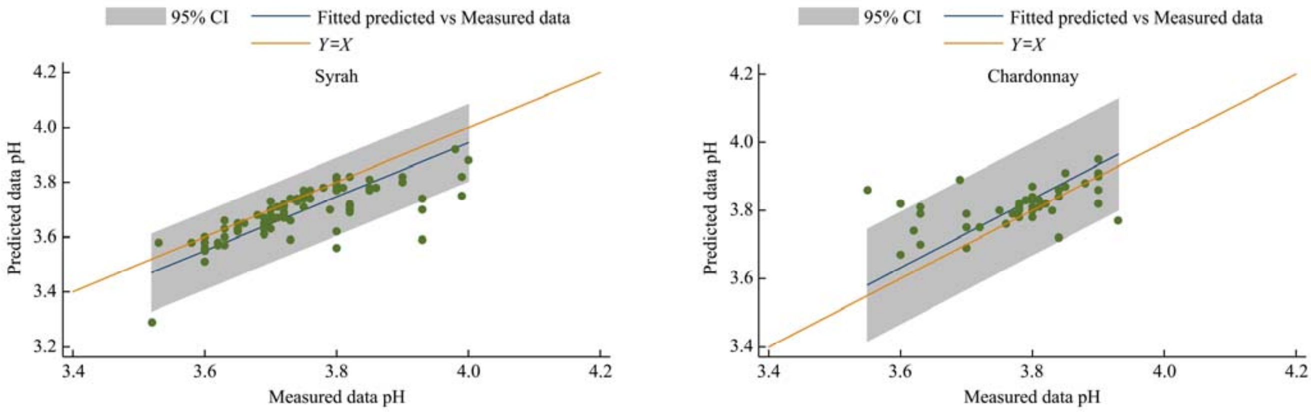

Figure 6 pH confidence interval for an individual forecast

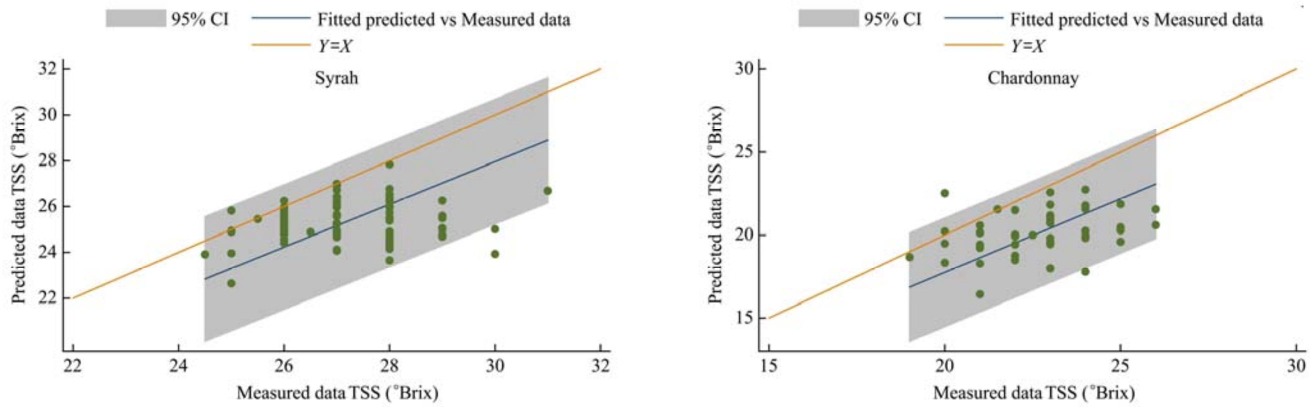

Figure 7 TSS confidence interval for an individual forecast

4 Discussion

The berry detachment force from the pedicel is a very important parameter in order to adjust the frequency of the shakers during mechanical harvest of grapes. The shaking frequency influences the production of juice mostly due to the energetic action of the shakers on grape clusters to allow berries detachment (Morris, 1998). The production of grape juice during harvest is to be limited because it causes the triggering of uncontrolled fermentations influencing the quality of wine especially if associated to ambient temperature higher than 30°C, as in Sicily in the harvest season (Catania et al., 2009; Pocock and Waters, 1998). Evaluating the berry detachment force therefore allows to appropriately adjust the shaking frequency, then obtaining a high quality product. Doing this evaluation in field through vis NIR spectroscopy, it would be possible to adjust the harvesting machine in order to preserve the future wine quality starting from harvest.

In the field of vis NIR spectroscopy applied to grapes for wine production, there are no studies evaluating the berry detachment force from the pedicel. Beghi et al. (2014), who evaluated grapes firmness during withering, affirm that the analysis of firmness through visible NIR spectroscopy and NIR spectroscopy often experienced difficulties due to the extreme variability of the berry mechanical characteristics but most of all because the estimation indexes are not directly associable with a chemical species (R^2 about 0.6 for firmness prediction). These considerations can be applied to our study where the evaluation of DF through vis NIRs gave uneven results for the two varieties and less supported models compared to the chemical parameters. In particular, we got a considerably different behavior between the two varieties considered. The vis NIR system prediction ability for DF of a red variety as Syrah was excellent ($R^2=0.87$; SECV/M = 0.362; bias/M = –0.109). The errors of prediction for a white variety as Chardonnay were conversely higher ($R^2=0.85$; SECV/M = 1.008; bias/M = –0.834). Costa et al. (2009) stated that the calibration transfer in the practice is a delicate procedure due to the different factors that influence calibration affecting the final results, and the cultivar is among them.

Our results confirm that vis NIR technology applied on wine grapes gives excellent performance in predicting pH for both varieties Syrah and Chardonnay ($R^2=0.99$), as stated by Cao et al. (2010) for different varieties (r = 0.9781 and RMSEP = 0.1257). Fernandes et al. (2015) obtained R^2 values equal to 0.82 and 0.73 for pH validation and test set, while González-Caballero et al. (2011) obtained a better performance with the bunch analysis rather than the must (r = 0.65; SECV = 0.21). Nogales-Bueno et al. (2014) obtained a standard error of cross validation SECV equal to 0.13 for red grapes and 0.11 for white grapes, values quite different from ours (respectively 0.087 and 0.007). NIR spectroscopy was also applied on Chardonnay cultivar (Larrain et al., 2008) showing a good potential in determining pH values of grapes with $R^2=0.874$. A study on table grapes (Baiano et al., 2012) gave $R^2=0.7965$ and 0.8961 respectively for the validation sets of white and red grapes. Overall, the studies considered above achieved interpretative models less robust than ours, with reference to the pH parameter.

The vis NIR predictive capacity for TSS in our study was higher than that recorded by Guidetti et al. (2010) for Nebbiolo grapes ($r=0.82$; RMSEP = 1.48) and by Larraìn et al. (2008) for Chardonnay grapes (R^2 = 0.874; RMSEV = 1.089). Nogales-Bueno et al. (2014) obtained SECV = 1.04 for red grapes and 1.10 for white grapes, confirming a strong validity of the models developed especially for the red varieties in analogy to what we obtained. Beghi et al. (2014) obtained R^2 = 0.68 and RMSECV = 1.46 for grape TSS determination during withering. Also the use of a NIR spectrometer in the range 1600-2400 nm gave a good prediction accuracy for TSS with $R^2=0.91$ and RMSECV = 1.51 (Urraca et al., 2015). The correlation coefficient and RMSEP for TSS were 0.9065 and 0.9579 in Cao et al. (2010). Again, Baiano et al. (2012) in the validation data set obtained $R^2=0.94$ for white grapes and 0.93 for red grapes.

Excellent results were also obtained on grapes bunches by González-Caballero et al. (2011) with R^2 = 0.94 for TSS, confirming that the NIR technology is suitable for evaluating the internal quality properties useful to determine the chemical changes that occur during maturation in vineyard in order to identify the optimum time for harvesting.

Overall, the studies mentioned above are in agreement with our findings and confirm the great potential of vis NIR technique for predicting the considered quality indices of the grapes.

5 Conclusions

The prediction capabilities of a portable vis NIR device operating in the wavelength range 600-1000 nm were tested on white and red grapes of cv. Chardonnay and Syrah *Vitis vinifera* L. to evaluate the main berry characteristics in non-destructive way before applying mechanical harvest. In particular, our study was aimed at estimating berry detachment force from the pedicel, pH and total soluble solids. Based on the authors' knowledge, the evaluation of the berry detachment force had never been performed using a vis NIR device neither with reference to other fruits. The strength of this study is precisely the parameter detachment force by virtue of its enormous importance in the mechanical harvesting of grapes. The previsions of the other parameters were widely consolidated through vis NIR spectroscopy and our study confirms what has already been determined by other authors.

The prospect of a rapid and non-destructive technique to be applied before mechanical harvest of grapes is really important considering that it is essential to harvest at the appropriate time and promptly to improve future wine quality. The results were very encouraging for cv. Syrah (red grapes) and need to be improved for cv. Chardonnay (white grapes). It might be desirable to promote the diffusion of vis NIR systems in the wine sector to better manage the production process exalting the wine quality.

References

Altieri, G., F. Genovese, A. Tauriello, and G. C. Di Renzo. 2017. Models to improve the non-destructive analysis of persimmon fruit properties by VIS/NIR spectrometry. *Journal of the Science of Food and Agriculture*, 97(15): 5302–5310.

Baiano, A., C. Terracone, G. Peri, and R. Romaniello. 2012. Application of hyperspectral imaging for prediction of physico-chemical and sensory characteristics of table grapes. *Computers and Electronics in Agriculture*, 87: 142–151.

Beghi, R., V. Giovenzana, S. Marai, and R. Guidetti. 2014. Rapid monitoring of grape withering using visible near-infrared spectroscopy. *Journal of the Science of Food and Agriculture*, 95(15): 3144–3149.

Beghi, R., A. Spinardi, L. Bodria, I. Mignani, and R. Guidetti. 2013. Apples nutraceutic properties evaluation through a visible and near-infrared portable system. *Food and Bioprocess Technology*, 6(9): 2547–2554.

Bosco, G. L. 2010. James L. Waters Symposium 2009 on near-infrared spectroscopy. *Trends in Analytical Chemistry*, 29(3): 197–208.

Bureau, S., D. Ruiz, M. Reich, B. Gouble, D. Bertrand, J. M. Audergon, and C. M. G. C. Renard. 2009. Rapid and non-destructive analysis of apricot fruit quality using FT-near-infrared spectroscopy. *Food Chemistry*, 113(4): 1323–1328.

Cao, F., D. Wu, and Y. He. 2010. Soluble solids content and pH prediction and varieties discrimination of grapes based on visible–near infrared spectroscopy. *Computers and Electronics in Agriculture*, 71(S): S15–S18.

Carrara, M., P. Catania, F. Pipitone, M. Vallone, and M. Salvia. 2007. Assessment of the pedicel detaching and crushing forces of grape berries to determine the optimal mechanical harvesting time. *Journal of Agricultural Engineering,* 3(8): 23–27.

Catania, P., M. Vallone, and F. Pipitone. 2009. Analysis of the main factors influencing the quality of wine from mechanically harvested grapes. *Journal of Agricultural Engineering*, 40(4): 27–30.

Catania, P., M. Alleri, A. Martorana, L. Settanni, G. Moschetti, and M. Vallone. 2014. Investigation on a tunnel pasteurizer for Nocellara del Belice table olives according to the Castelvetrano method. *Grasas Aceites*, 65(4): e049, 1-13.

Cayuela, J. A. 2008. Vis/NIR soluble solids prediction in intact oranges (Citrus sinensis L.) cv. Valencia Late by reflectance. *Postharvest Biology and Technology,* 47(1): 75–80.

Clary, C. D., R. E. Steinhauer, J. E. Frisinger, T. E. Peffer. 1990. Evaluation of machine-vs. hand-harvested Chardonnay. *American Journal of Enology and Viticulture*, 41(2): 176–181.

Costa, G., M. Noferini, G. Fiori, and P. Torrigiani. 2009. Use of Vis/NIR Spectroscopy to assess fruit ripening stage and improve management in post-harvest chain. In *New Trends in Postharvest Management of Fresh Produce I. Fresh Produce 3*, ed. D. Sivakumar, Special issue 1, 35–41. UK: Global Science Books.

Cozzolino, D., and R. G. Dambergs. 2010. Instrumental analysis of grape, must and wine. In *Managing Wine Quality*, ed. A. Reynolds, vol. 1. Cambridge, UK: Woodhead Publishing.

Ferrer-Gallego, R., J. M. Hernández-Hierro, J. C. Rivas-Gonzalo, and M. T. Escribano-Bailón. 2013. Evaluation of sensory parameters of grapes using near infrared spectroscopy. *Journal of Food Engineering*, 118(3): 333–339.

Fernandes, A. M., C. Franco, A. Mendes-Ferreira, A. Mendes-Faia, P. L. D. Costa, and P. Melo-Pinto. 2015. Brix, pH and anthocyanin content determination in whole Port wine grape berries by hyperspectral imaging and neural networks. *Computers and Electronics in Agriculture,* 115(1): 88–96.

González-Caballero, V., D. Pérez-Marín, M. I. López, and M. T. Sánchez. 2011. Optimization of NIR spectral data management for quality control of grape bunches during on-vine ripening. *Sensors*, 11(6): 6109–6124.

González-Caballero, V., M. T. Sánchez, J. Fernández-Novales, M. I. López, and D. Pérez-Marín. 2012. On-vine monitoring of grape ripening using near-infrared spectroscopy. *Food Analytical Methods*: 5(6): 1377–1385.

Guidetti R., A. Donato, and C. Mazzini. 2005. NIR portable device use in a logistic platform: productivity and performance analysis. *V International Postharvest Symposium*, 682: 1341–1346.

Guidetti, R., R. Beghi, and L. Bodria. 2010. Evaluation of grape quality parameters by a simple VIS/NIR system. *Transactions of the ASABE*, 53(2): 477–484.

Kawano, S., K. Fujiwara, and M. Iwamoto. 1993. Non-destructive determination of sugar content in Satsuma mandarin using near infrared (NIR) transmittance. *Journal of the Japanese Society for Horticultural Science*, 62(2): 465–470.

Kerridge, G., and A. Antcliff. 1999. *Wine Grape Varieties*. Victoria, Australia: CSIRO.

Lammertyn, J., B. Nicolai, K. Ooms, V. De Smedt, and J. De Baerdemaeker. 1998. Non-destructive measurement of acidity, soluble solids, and firmness of Jonagold apples using NIR spectroscopy. *Transactions of the ASAE*, 41(4): 1086–1094.

Larrain, M., A. R. Guesalaga, and E. Agosin. 2008. A multipurpose portable instrument for determining ripeness in wine grapes using NIR spectroscopy. *IEEE Transactions on Instrumentation and Measurement*, 57(2): 294–302.

Letaief, H., L. Rolle, and V. Gerbi. 2008. Mechanical behavior of winegrapes under compression tests. *American Journal of Enology and Viticulture*, 59(3): 323–329.

Lv, G., H. Yang, N. Xu, and A. M. Mouazen. 2012. Identification of less-ripen, ripen, and over-ripen grapes during harvest time based on visible and near-infrared (Vis-NIR) spectroscopy. In *2nd International Conference on Consumer Electronics, Communications and Networks (CECNet)*, 1067–1070. Three Gorges, China, 21-23 April.

McGlone, V. A., R. B Jordan, and P. J. Martinsen. 2002.Vis/NIR estimation at harvest of pre- and post-storage quality indices for ‘Royal Gala’ apple. *Postharvest Biology and Technology*, 25(2): 135–144.

McGlone, V. A., D. G. Fraser, R. B. Jordan, and R. Künnemeyer. 2003. Internal quality assessment of mandarin fruit by VIS/NIR spectroscopy. *Journal of Near Infrared Spectroscopy*, 11(5): 323–332.

Menesatti, P. 2007. In-field spectrophotometric measurement to estimate maturity stage of wine grapes. In *Proc. SPIE 6761, Optics for Natural Resources, Agriculture, and Foods II*, Vol. 6761, 676118. Boston, US, 9-12 September.

Miller, W. M., and M. Zude-Sasse. 2004. NIR-based sensing to measure soluble solids content of Florida citrus. *Applied Engineering in Agriculture*, 20(3): 321–327.

Morris, J. R. Factors influencing grape juice quality. 1998. *HortTechnology*, 8(4): 471–478.

Nogales-Bueno, J., M. H. Hernàndez-Hierro, F. J. Rodrìguez-Pulido, and F. J. Heredia. 2014. Determination of technological maturity of grapes and total phenolic compounds of grape skins in red and white cultivars during ripening by near infrared hyperspectral image: A preliminary approach. *Food Chemistry*, 152: 586–591.

Osborne, S. D., and R. Künnemeyer. 1999. A low-cost system for the grading of kiwifruit. *Journal of Near Infrared Spectroscopy*, 7(1): 9–15.

Park, B., J. A. Abbott, K. J. Lee, C. H. Choi, and K. H. Choi. 2003. Near-infrared diffuse reflectance for quantitative and qualitative measurement of soluble solids and firmness of delicious and gala apples. *Transactions of the ASAE*, 46(6): 1721–1731.

Piazzolla, F., M. L. Amodio, and G. Colelli. 2013. The use of hyperspectral imaging in the visible and near infrared region to discriminate between table grapes harvested at different times. *Journal of Agricultural Engineering*, 44(2): e7, 49–55.

Pocock, K. F., and E. J. Waters. 1998. The effect of mechanical harvesting and transport of grapes, and juice oxidation, on the protein stability of wines. *Australian Journal of Grape and Wine Research*, 4(3): 136–139.

Porep, J. U., M. E. Erdmann, A. Körzendörfer, D. R. Kammerer, and R. Carle. 2014. Rapid determination of ergosterol in grape mashes for grape rot indication and further quality assessment by means of an industrial near infrared/visible (NIR/VIS) spectrometer - A feasibility study. *Food Control*, 43: 142–149.

Porep, J. U., A. Mattes, M. S. P. Nikfardjam, D. R. Kammerer, and R. Carle. 2015. Implementation of an on-line near infrared/visible (NIR/VIS) spectrometer for rapid quality assessment of grapes upon receival at wineries. *Australian Journal of Grape and Wine Research*, 21(1): 69–79.

Ribera-Fonseca, A., M. Noferini, E. Jorquera-Fontena, and A. D. Rombolà. 2016. Assessment of technological maturity parameters and anthocyanins in berries of cv. Sangiovese (Vitis vinifera L.) by a portable vis/NIR device. *Scientia Horticulturae*, 209: 229–235.

Saranwong, S., J. Sornsrivichai, and S. Kawano. 2004. Prediction of ripe-stage eating quality of mango fruit from its harvest quality measured nondestructively by near infrared spectroscopy. *Postharvest Biology and Technology*, 31(2): 137–145.

Slaughter, D. C., D. Barrett, and M. Boersig. 1996. Nondestructive determination of soluble solids in tomatoes using near infrared spectroscopy. *Journal of Food Science*, 61(4): 695–697.

Steuer, B., H.Schulz, and E. Làger. 2001. Classification and analysis of citrus oils by NIR spectroscopy. *Food Chemistry*, 72: 113–117.

Torchio, F., E. Cagnasso, V. Gerbi, and L. Rolle. 2010. Mechanical properties, phenolic composition and extractability indices of Barbera grapes of different soluble solids contents from several growing areas. *Analytica Chimica Acta*, 660(1-2): 183–189.

Urraca, R., A. Sanz-Garcia, J. Tardaguila, M. P. Diago. 2015. Estimation of total soluble solids in grape berries using a hand-held NIR spectrometer under field conditions. *Journal of the Science of Food and Agriculture*, 96(9): 3007–3016.

Vallone, M., F. Bono, M. Alleri, E. Barone, and P. Catania. 2016. Quality evaluation of “Tardivo di Ciaculli” mandarin in post-harvest processing on an industrial scale using a portable vis/NIR device. *Transactions of the ASABE*, 59(2): 465–473.

Zude, M., M. Pflanz, C. Kaprielian, and B. L. Aivazian. 2008. NIRS as a tool for precision horticulture in the Citrus industry. *Biosystems Engineering*, 99(3): 455–459.