THE ESTIMATION OF CLIMATE CHANGE IMPACTS ON THE ADOPTION OF SUSTAINABLE PRODUCTION PROCESSES IN VITICULTURE: A MULTIDISCIPLINARY APPROACH

Maria DE SALVO, Roberta CAPITELLO, Diego BEGALLI
Department of Business Administration, University of Verona; email: diego.begalli@univr.it; L.ge Porta Vittoria 41, Verona, Italy

Abstract
This research is aimed to assess the climate change impacts on the viticulture applying an interdisciplinary approach that simultaneously considers climatic, physiological, phenological, viticultural and oenological aspects. The relationships between climate and grapevine physiology and phenology are analysed. Moreover the effects on the berry composition, the grape production and the wine quality determined by the spatial context, the grape variety and the vintage are accounted. Data from experimental vineyards are compared with farms' data in order to account the effects on the vineyard performances and sustainability attributable to vine growers choices and strategies.
Keywords
climate change; wine; multidisciplinary approach

Introduction

The impacts of weather and climate on the grape growing are complex and controversial, and numerous researchers have forecasted that the ongoing climate change will likely produce winners and losers among the winegrowers (see for instance: Anshenfelter and Storchmann, 2014), due to the opposite effects on the quantity and the quality of wine. Market prices and winegrowers' revenues are extremely sensitive to the weather conditions. In the next future global warming could lead to geographical modifications of the viticulture, favouring the grape cultivation in the areas close to the North and the South Poles (Fraga et al., 2013).

Numerous studies concern the relationships between wine and climate change. Several scholars focus on the physical impacts, considering the role of each climate variable, such as temperature, CO_2 concentration, and water availability (Bindi et al., 1996; Ashenfelter and Storchmann, 2014). Other scholars (Haeger and Storchmann, 2006; Ashenfelter and Storchmann, 2010a; Ashenfelter and Storchmann, 2010b; Marinoni et al., 2012) analyse the economic effects, in terms of total production and yields, quality, prices, revenues and profits variations. Other studies (Battaglini et al., 2009; Bernetti et al., 2012; Nicholas and Durham, 2012; Vink et al., 2012; Lereboullet et al., 2013) consider the winegrowers' perception and their ability to promote adaptation strategies aimed to face climate change effects.

A common criticism to all these studies is that they take into account only some aspects of the problem. Robust forecasts on the climate change effects should derive from analysis able to consider all the phenomena that have a relevant role in the determination of the relationships between the climate change and the wine production. In this regard a multidisciplinary approach able to analyse the impacts on the grape physiology and phenology, yields and quality of berries and wine is needed in order to identify the most relevant factors that influence the winegrowers' performance in specific climatic contexts.

This paper presents the preliminary results of a research aimed to assess the climate change impacts on the wine industry through an interdisciplinary approach that considers climatic, physiological, phenological, viticultural and oenological variables. As shown by previous studies climate change affects the grapevine physiology and phenology (Caprio and Quamme, 2002; Gouveia et al., 2009; Santos et al., 2011; Santos et al., 2013). This affects grape quantity and quality and, consequently, the wine production. The winegrowers' behaviour plays a key role because they face the climate change impacts through modifications of the production technics. As a consequence, some discrepancies between predicted and observed yields and wine peculiarities could occur. If the model used to forecast the effects of climate change on wine quantity and quality is able to consider all the physiological and phenological phenomena involved in these modifications, these discrepancies can be attributed to the human component.

This paper aims to achieve the following objectives. As a first, it aims to analyse the relationship between the climate and the grapevine physiology and phenology, highlighting which components are relevant and how the different phenomena are related each other. Moreover, it is devoted to study the effects of spatial contexts, vines, and vintages on the berry composition and the grape production in order to highlight the circumstances in which climate change can become an opportunity for the wine industry. In fact, climate changes can generate improvements of the wine quality in delimitated spatial contexts and for specific varieties. A second objective of the research is the analysis of factors that are responsible of discrepancies between predicted and observed yields at the farm level.

In order to achieve these objectives the Moldavian viticulture is considered as case study. Moldavia is one of the most important Rumanian viticulture areas, especially for the production of white wine. In this area several local and international grape varieties are cultivated. Moreover, weather and soil characteristics are different between the northern and the southern counties. As a consequence, the case study appears particularly suitable for the assessment of the climate change impacts on the viticulture.

The rest of the paper is articulated as follow. Section 2 concerns the methodology and section 3 reports and discusses the results. Section 4 concludes.

1. Methodology

The study adopts an interdisciplinary approach. It analyzes data about climate, grape physiology and phenology, berries quantity and quality, and wine quality, and estimates the correlations between different classes of indices. Table 1 and 2 report these indices. Spearman's rank correlation coefficients were calculated to analyze significance, direction and intensity of each relationship. Only results on a selection of indices are reported in this paper. The selected indices are highlighted in bold in Table 1 and 2.

An ANOVA analysis was carried out in order to determine the factors influencing the value of each index (Table 3). A different specification was adopted in relation to the type of index and the nature of available data.

Yields were estimated using data collected from experimental vineyards, which are compared with farms' data in order to highlight the presence of discrepancies due to the effects of the human component. Yields for the experimental vineyards were determined at the harvest time.

Climatic, physiological and phenological data concerning the growing periods 2009-10, 2010-11 and 2011-12 were collected at different times of the growing season in three experimental fields, respectively located in Iasi, Cotnari and Torgu Bujour. Seven different varieties (Babeasca, Francusa, Grasa de Cotnari, Riesling Italian, Feteasca Alba and Regale and Tamaiosa Romaneasca) are cultivated in these experimental fields. Harvested grapes were analysed to assess quality and quantity indices. Moreover, the grapes were fermented to produce wine and it made possible to measure also oenological parameters.

Data on farm characteristics, climate change winegrowers' perceptions and their propensity to adopt specific strategies were collected through a survey carried out on a sample of 55 winegrowers, with 99 vineyards located in the Moldova wine region. Respondents were chosen among the associates of the Romanian 'Asociatia Producatorilor si Exportatorilor de Vinuri' (APEV). Data concerns three consecutive years (2010–2012). The sample is representative of the statistical population of Moldova winegrowers.

Table 1 Bioclimatic indices

Index	Reference	Formula	Description
Real heliothermic index	Branas (1974)	**∑((Tavg-10°C)*∑ Ie*10^-6)** Tavg: Average temperature*; Ie: annual effective insolation	This index indicates the interaction between light and temperature.
Hydrothermic coefficient	Branas et al. (1946)	**∑ (Tavg* Pgs)** Tavg: average temperature*; Pgs: precipitations (mm)*	This index refers to the interaction of temperature, light and humidity.
Bioclimatic viticulture index	**Costantinescu et al. (1964)**	**(T*I)/(P+gg+10)** T: sum of the temperature degrees*; I: the hours of effective sun exposure*; P: precipitation*; gg: length in days of the growing period.	This index refers to the interaction of temperature, light and humidity considering the length of the growing season.
Oenoloclimatic aptitude index	Teodorescu (1977)	**T+I-(P-250)** T: sum of the temperature degrees*; I: the hours of effective sun exposure*; P: precipitation*	This index is used for establishing the degree of climatic favourability of a region for grape anthocyanin's synthesis - for the production of red wines.
Aridity index	De Martonne (1926)	**P/(Tm + 10)** P: total annual precipitation; Tm: mean annual temperature.	This index estimates the degree of aridity of an area for one year.

* measured during the period 01.04-30.09.

Table 1. Physiological, phenological, grape quality and quantity, and wine quality indices

Class of indices	Index	Unit of measurement
Physiological indices	**Photosynthesis rate**	μmolm^{-2} s^{-1}
	Water Use Efficiency	μml/mmol
Phenological indices	Length of the I^ phase: from bleeding/weeping to budburst	Days
	Length of the II^ phase: from budburst to flowering	
	Length of the III^ phase: from flowering to fruit set	
	Length of the VI^ phase: from fruit-set to veraison	
	Length of the V^ phase: from veraison to bunch maturation (harvesting)	
	Length of the growing season	

Class of indices	Index	Unit of measurement
Grape quantity indices	Yield/plant	kg
	Weight of the bunch (WB)	g
	Predicted yield	t/ha
	Relative fertility (RF)	n.inflorescences/n.shoots
	Relative productivity (RP)	RF*$\overline{\mathbf{W}}$
Grape quality indices	**Sugar content**	g/l
	Total acidity	g/l of tartaric acid
	Gluco-acidimetric index	Sugar content/Total acidity
Wine quality indices	**Alcoholic content**	% vol
	Total acidity	g/l of acetic acid
	Density (at 20°C)	g/ml
	Sugar content	g/l
	Dry extract	g/l
	Total sulfur dioxide	mg/l

Table 3. ANOVA by class of indices

Group of indices as a proxy of:	Type of ANOVA	Variables
Climate	Two-way	• Experimental field • Vintage
Grapevine physiology	Four – way	• Cultivated grape variety • Experimental field • Vintage • Phenological phase
Grapevine phenology	Three – way	• Cultivated grape variety • Experimental field • Vintage
Grape quantity	Three – way	• Cultivated grape variety • Experimental field • Vintage
Grape quality	Three – way	• Cultivated grape variety • Experimental field • Vintage
Wine quality	Three – way	• Cultivated grape variety • Experimental field • Vintage

2. Results

Results of the Spearman's correlation analysis are reported in Table 4. Climate affects positively the grape physiology, both in terms of Photosynthetic Rate (PR) and Water Use Efficiency (WUE). The correlation coefficients between the Bioclimatic viticulture index and PR and WUE equal 0.6986 and 0.6595 respectively. These physiological processes are also positively correlated to each other: an improvement of the PR implies a better efficiency in the water usage ($\rho = 0.9204$).

The grape quality is affected by the climate in terms of total acidity ($\rho = 0.7205$), due to its effects on the photosynthesis and the plant water balance. PR and WUE are significantly and positively correlated with the grape total acidity. The Spearman correlation coefficients equal to 0.7838 and 0.7725 respectively. The grape sugar content is not significantly affected by climate and plant physiology and phenology. This result is confirmed also using all the others climatic indices. The climatic factors that should affect the grape sugar content are not constraints in the study area. This is also supported by non-significant effect of climate on the grape quantity. The analysis shows that the yield is also independent of the length of the growing season, and of the grape phenology. The quantity of grape is significantly correlated only with the grape sugar content ($\rho = -0.4088$).

The climate affects the wine quality: an increase of the bioclimatic viticulture index is associated to an increase of the wine alcoholic content ($\rho = 0.5896$) and to a decrease of the wine sugar content ($\rho = -0.4227$). The latter depends also on the grape total acidity ($\rho = -0.3738$).
The climate affects the duration of the cycle of production, which is inversely correlated to the bioclimatic viticulture index ($\rho = -0.5861$). The grape phenology also affects the grape total acidity: the value of the correlation coefficient suggests that in the presence of a longer cycle, the grape presents a lower value of the total acidity ($\rho = -0.6352$). The length of the growing season, seems to affect also the wine sugar content ($\rho = 0.3667$).
Table 5 reports the results of the ANOVA analysis. The index variability depends, for the majority of the groups of indices, on the vintage, which can be considered a proxy of climate conditions. The vintage explains the higher quote of variability of all the physiological and phenological indices and some of grape quality (total acidity and gluco-acidimetric index) and wine quality indices (dry extract and total sulfure dioxide).
Conversely, the variety seems to be an important factor in the explanation of all the yields indices, such as the grape sugar content and the wine total acidity. The spatial context does not play a relevant role. It explains a little part of the index variability for the bioclimatic, the physiological and some of the production quantity indices (yield/plant; weight of bunch and relative productivity). This factor significantly explains some wine quality indices, such as the alcoholic content, the wine density and the dry extract.
Table 6 reports the observed and predicted yields at the farm level. Results show that the growing period 2009-10 determined positive production performance for all farms, except for those who cultivate the Francusa variety, which is the only one with observed yields lower than predicted yields (-1.33 t/ha). The other two years were characterized by low production performances compared to expectations. The varieties Italian Riesling (-6.43 t/ha), Feteasca Alba (-4.19 t/ha), and Grasa de Cotnari (-2.24 t/ha) show the worst performance for the year 2010-11, and the varieties Francusa (-5.71 t/ha), Italian Riesling (-2.27 t/ha), Feteasca Regala (-2.15 t/ha) and Feteasca Alba (-1.21 t/ha) for the year 2011-12.
Figures 1, 2 and 3 report temperatures,, precipitations and sunshine hours data measured during the three years considered in this analysis. Weather indices show that the grape growing period 2009-10 was a rainy year, whereas the last two years were characterized by an increase of the temperature range and sunshine hours.
As a consequence, in years characterized by weather conditions that favour best production performance (rainy years) farms' yields are higher than expectations. Oppositely, such as for years 2010-11 and 2011-12, observed yields are lower than expectations.
Table 8 shows that these relationships are significant. In fact the Spearman correlation coefficients among temperature, precipitations, and the difference between the observed and the predicted yields are all significant assuming $\alpha<0.01$. In particular the yield gap increases if precipitations increase ($\rho = 0.400$) and decrease if temperatures increase, both for the average ($\rho = -0.234$), the maximum ($\rho = -0.199$) and the minimum ($\rho = -0.327$) value. The correlation with the sunshine hours, oppositely, is un-significant.

Table 4. Spearman correlation coefficients (ρ) between indices

	Bioclimatic viticulture index	Photosynthesis rate	WUE	Length of the growing season	Yield	Grape sugar content	Grape total acidity	Alcoholic content
Photosynthesis rate	0.699 *							
WUE	0.660 *	0.920 *						
Length of the growing season	-0.586 *	-0.813 *	-0.718 *					
Yield	-0.045	-0.033	0.044	0.168				
Grape sugar content	0.086	0.033	-0.036	-0.237	-0.409 **			
Grape total acidity	0.720 *	0.784 *	0.772 *	-0.635 *	0.126	-0.227		
Alcoholic content	0.590 *	0.261	0.281	-0.127	-0.324	-0.068	0.310	
Wine sugar content	-0.423 **	-0.326	-0.215	0.367 **	-0.178	-0.193	-0.374 **	0.091

Legenda: *significant at α<1%; ** significant at α<5%.

Table 5. Percentage of variance explained by factors selected through the ANOVA

Class on indices	Index	Variety	Experimental field	Vintage	Phenological phase	Residual
Bioclimatic indices	Heliothermal real index		5% (*)	92% (*)		3%
	Hydrothermal index		7% (*)	76% (*)		17%
	Bioclimatic viticulture index		7% (*)	72% (*)		21%
	Oenological aptitude index		2% (*)	91% (*)		7%
	Aridity index		0%	88% (*)		12%
Physiological indices	Photosynthesis rate	2%	7% (**)	28% (*)	3%	60%
	Water Use Efficiency (WUE)	5%	5% (*)	21% (*)	5% (**)	64%
Phenological indices (length in days of each phase of the growing season)	From bleeding/weeping to budburst	2%	16% (*)	46% (*)		36%
	From budburst to flowering	1%	18% (*)	22% (*)		59%
	From flowering to fruit set	13%	3%	14% (**)		70%
	From fruit-set to veraison	2%	1%	87% (*)		10%
	From veraison to bunch maturation (harvesting)	2%	16% (*)	46% (*)		36%
Quantity indices	Yield/plan	35% (*)	11% (*)	33% (*)		21%
	Weight of the bunch	79% (*)	6% (*)	4% (*)		11%
	Predicted yield per hectare	37% (*)	4%	28% (*)		31%
	Relative fertility	51% (*)	4%	6%		39%
	Relative productivity	28% (*)	20% (*)	8%		44%

Class on indices	Index	Variety	Experimental field	Vintage	Phenological phase	Residual
Grape quality indices	Sugar content	17% (**)	4%	1%		78%
	Total acidity	18%	0%	54% (*)		28%
	Gluco-acidimetric index	14%	3%	25% (*)		58%
Wine quality indices	Alcholic content	12%	35% (*)	16% (*)		37%
	Total acidity	33% (**)	9%	9% (**)		49%
	Density	9%	26% (*)	26% (*)		39%
	Sugar content	16%	17%	12% (**)		55%
	Dry extract	6%	22% (**)	25% (*)		47%
	Total sulfur dioxide	13%	4%	56% (*)		27%

Legenda: *significant at α<1%; ** significant at α<5%.

Table 6. Predicted and observed yields (t/ha)

	2010		2011		2012	
	Predicted	Observed	Predicted	Observed	Predicted	Observed
Feteasca Alba	7.17	7.37	11.85	7.66	8.83	7.63
Feteasca Regala	7.18	7.73	6.40	8.00	10.29	8.14
Francusa	8.67	7.33	7.75	7.83	12.71	7.00
Grasa de Cotnari	5.76	6.71	9.37	7.13	6.57	6.43
Riesling Italian	4.95	6.08	13.45	7.02	9.55	7.28
Tamaioasa Romaneasca	7.18	9.17	9.00	9.20	8.31	9.13

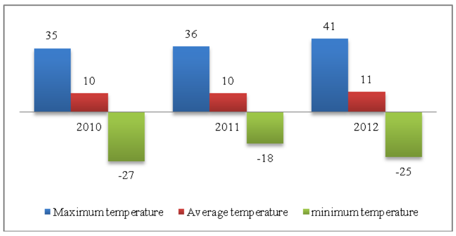

Fig. 1 Average, minimum and maximum temperature per year

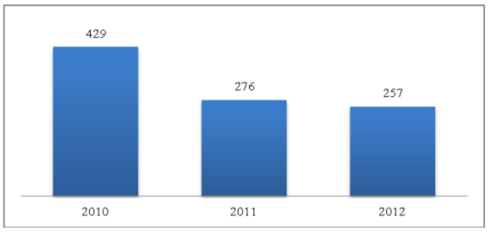

Fig. 2 Precipitations per year, during the growing season.

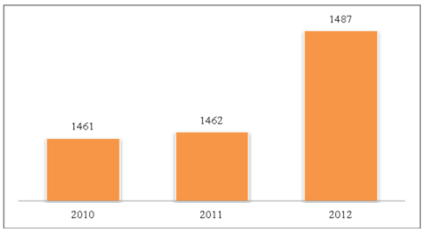

Fig. 3 Sunshine hours per year during the growing season,

Table 7. Spearman correlation coefficients (ρ) between the weather variables and the yield gap

	$Yield_{Observed} - Yield_{Predicted}$	
Precipitations during the growing season	0.400	*
Sunshine hours	0.053	
Average annual temperature	-0.234	*
Minimum temperature observed during the growing season	-0.327	*
Maximum temperature observed during the growing season	-0.199	*

Legend: *significant at $\alpha<1\%$; ** significant at $\alpha<5\%$.

Concluding remarks

This article reports the main results of the estimation of impacts of climate change on the viticulture industry using an interdisciplinary approach. Climatic, phenological, physiological, viticulture and oenological indices were analysed to highlight significance, direction and intensity of the relationships between these dimensions. The effects of vintage, variety, spatial context and phenological phase were also accounted to evidence the circumstances in which wine performances should improve, both in quantitative and qualitative terms. Finally, annual predicted yields estimated by experimental vineyards' data were compare to observed yields at farm level in order to explain the role of the human factor and to analyse the efficiency of strategies implemented by wine growers to face climate change impacts.

The results offer different points of discussion. As a first, the adoption of an interdisciplinary approach is required in order to analyse all the relevant phenomena that impact on the response of the wine growers to the weather scenario and the climate. In relation to the specific context used as case study (Moldavian viticulture, Romania), the climate affects the quality of wine, both in terms of alcoholic and sugar content. The analysis highlights the presence of a positive correlation between the bioclimatic viticulture index and the grape physiology, both in terms of photosynthesis rate and efficiency of water use. Oppositely, an increase of this climatic index is associated to decreases of the length of the growing season. The yield seems to be independent on the climate, probably because precipitations, that play a key role in the determination of this index, is not a constraining factor for the Moldavian viticulture.

The variability of the grape yield parameters depends on the variety. Only in few cases the vintage plays a relevant role (yield/plant; predicted yield per hectare). The variability of oenological parameters is most dependent on the annual weather scenario. The vintage has a primary role in explaining the variability of the sugar content, the density and the total sulphur dioxide. The spatial variability is important to explain some indices (alcoholic content; density; dry extract). Finally, the variety is relevant in the explanation of the variability of the wine total acidity.

The comparison between observed and predicted shows the relevant role played by the human component on the wine production performance. During the years characterized by favorable weather conditions observed yields exceed expected yields for a large part of the varieties. Oppositely, during the years suitable to obtain best quality wines, the observed yields are lower than expected yields.

The research also presents limitations that should be considered in order to address future development. It does not consider the differences between experimental vineyards and farms' considered in the survey as it concerns the type of soil and the vineyard training system. Both these factors could play a relevant role in the determination of the yields.

The analysis could be further improved through a more detailed study about the role of the human component mainly in relation to the winegrowers' ability in the adoption of technological choices and management strategies suitable to face the climate change impacts. Also the heterogeneity in terms of educational level, perception of climate change impacts and farm structure aspects should be considered in more detail. As it concerns the analysis of the relationships between the climate, grape physiology and phenology, grape and wine performances, the adoption of a structural equation models could improve the quality of results because it would allow the study to simultaneously analyze the effects determined by all the considered dimensions.

Despite these limitations, the study offers useful suggestions for policy makers in order to promote the adoption of policies aimed to increase the resilience of the Romanian viticulture to climate change. In the same time the study contributes to define guidelines for farmers aimed to stimulate the adoption of best practices to face the climate change impacts on the Romanian wine industry.

References:

1. Ashenfelter O., Storchmann K. (2014). Wine and Climate Change, *AAWE WORKING PAPER No. 152* (http://www.wine-economics.org/aawe/wp-content/uploads/2014/03/AAWE_WP152.pdf).
2. Ashenfelter O., Storchmann K. (2010a). Measuring the economic effect of global warming on viticulture using auction, retail and wholesale prices. *Review of Industrial Organization*, 37: 51-64.
3. Ashenfelter, O., Storchmann K. (2010b). Using a hedonic model of solar radiation to assess the economic effect of climate change: the case of Mosel valley vineyards. *The Review of Economics and Statistics*, 92(2): 333-349.
4. Battaglini, A., Barbeau, G., Bindi, M., & Badeck, F.W. (2009). European winegrowers' perceptions of climate change impact and options for adaptation, *Regional Environmental Change*, 9 (2), 61-73.
5. Bernetti J. Menghini S., Marinelli N., Sacchelli S., & Alampi Sottini V. (2012). Assessment of climate change impact on viticulture: Economic evaluations and adaptation strategies for the Tuscan wine sector, *Wine Economics and Policy*, 1: 73-86.
6. Bindi, M., Fibbi, L., Gozzini, B., Orlandini, S., & Miglietta, F. (1996). Modelling the impact of future climate scenarios on yield and yield variability of grapevine, *Climate Research*, 7 (3), 213-224.
7. Caprio, J.M., & Quamme, H.A. (2002). Weather conditions associated with grape production in the Okanagan Valley of British Columbia and potential impact of climate change, Canadian Journal of Plant Science, 82 (4), 755-763. Chevet, J.-M., Lecocq, S. and Visser, M. (2011). Climate, grapevine phenology, wine production, and prices: Pauillac (1800–2009). *American Economic Review: Papers and Proceedings*, 101(3), 142-146.

8. Fraga H, Malheiro AC, Moutinho-Pereira J, Santos JA. (2013). Future scenarios for viticultural zoning in Europe: ensemble projections and uncertainties, *International Journal of Biometeorology*, 57(6): 909-25.
9. Gouveia C., M. L. R. Liberato, C. DaCamara, R. M. Trigo (2009). *Interannual Variability of Vineyards in Northeast Portugal*. 33rd International Symposium on Remote Sensing of Environment (ISRSE) – Sustaining the Millennium Development Goals, Stresa, Italy.
10. Haeger, J., Storchmann, K. (2006). Prices of American Pinot Noir: climate, critics, craftsmanship. *Agricultural Economics*, 35: 67-78.
11. Irimia L., Patriche C.V., H. Quénol H., 2013. Viticulture zoning: the vineyard's climate suitability assessment, *Cercetări Agronomice în Moldova*, XLVI (3/155): 95-106.
12. Lereboullet, A.-L., Beltrando, G., Bardsley, D.K., & Rouvellac, E. (2013). The viticultural system and climate change: coping with long-term trends in temperature and rainfall in Roussillon, France, *Regional Environmental Change*, pp. 1-16. Article in Press.
13. Marinoni O., Navarro Garcia J., Marvanek S., Prestwidge D., Clifford D., Laredo L.A. (2012). Development of a system to produce maps of agricultural profit on a continental scale: An example for Australia, *Agricultural Systems*, 105(1): 33–45.
14. Nicholas, K.A., & Durham, W.H. (2012). Farm-scale adaptation and vulnerability to environmental stresses: Insights from winegrowing in Northern California, *Global Environmental Change*, 22 (2), 483-494.
15. Santos, J.A., Malheiro, A.C., Karremann, M.K., & Pinto, J.G. (2011). Statistical modeling of grapevine yield in the Port Wine region under present and future climate conditions, *International Journal of Biometeorology,* 55 (2), 119-131.
16. Santos, J.A., Grätsch, S.D., Karremann, M.K., Jones, G.V., & Pinto, J.G. (2013). Ensemble projections for wine production in the Douro Valley of Portugal, *Climatic Change*, 117 (1-2), 211-225.
17. Stanescu C., 1960. Indicele gluco-acidimetric al strugurilor-criteriu de apreciere tehnologica a soiurilor de vita de vie, *Gradina, Via si Livada*, 9 (10): 35-43.
18. Vink, N., Deloire, A., Bonnardot, V., & Ewert, J. (2012). Climate change and the future of South Africa's wine industry, *International Journal of Climate Change Strategies and Management*, 4 (4), 420-441.