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Resistance and resilience to changing climate of Tuscany and Valpolicella wine grape growing regions in Italy

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Abstract. Global climate change poses new challenges for plant species, including new and complex combinations of environmental conditions to which plants should adjust and adapt. Mediterranean ecosystems are recognized biodiversity hotspots, but are also global climate change hotspots due to the concerted action of multiple environmental drivers. The Italian Peninsula presents a wide range of all these site-related elements influencing grapevine performance. From a climatic perspective, it delivers a relatively large set of mesoclimates, spanning from dryer regions, in the inner south, to more humid regions, in the northwest and northeast. Topography and soils are also quite distinct throughout the peninsula, ranging from extended flatland areas to steep mountainous regions, each with very different soil characteristics, which may influence crop selection and settlements in each region. All these elements are reflected in the different varieties grown throughout the peninsula.

This study aims to provide an improved assessment of the practical adaptation options for the viticulture of Tuscany and of Valpolicella and what could be the strength and resilience to climate change of grapevine varieties in these areas. According to the models tested, Italian viticulture is able to adapt better than other countries to global warming, as the placing at various altitudes up in the high hills and mountains sets off the mechanism called resilience.

1. Introduction

Of all drinks, wine is the only one with a symbolic value.

In Mediterranean Greco-Roman civilizations, where the Gods had a human appearance, there was a link between the natural and the divine.

The domestication of the *Vitis* genus with the obtaining of the *vinifera* species that occurred as described by the Old Testament in the Ararat region, irradiated from its cradle in the Pontus region to the Fertile Crescent and was then spread by the Greco-Roman civilisation. The Christian culture syncretically adopted the rituals.

The caravels and colonisation from the Mediterranean during the 16th and 17th centuries, took the *Vitis vinifera* to the New World.

Viticulture found favourable climate conditions and latitudes there, i.e. those that allow a full plant cycle of the vine, as it is a long-day plant. The photoperiod determines the hormonal cycle, the basis of the metabolic functions of the plant's rest period, budding, flowering, veraison and the accumulation of reserves for the subsequent cycle.

The historic vineyard areas, where viticulture has adapted, produce typical and famous wines.

New viticulture either refers to a historical and cultural heritage (viticulture taken to Serra Gaúcha from the Veneto) or to brands where the name of the variety prevails (Chardonnay, Cabernet Sauvignon, Syrah, etc.), a mirror effect of the original historic areas (Bordeaux, Champagne and the Loire Valley).

The current prevalence of mass retail (80% of wines are sold off-trade) concentrates on few wine types.

Therefore, the pedoclimatic indices reflect a reallocation policy of vineyard areas in parameters respecting the new styles of products requested by consumers.

An example of this is the relocation of Californian viticulture to Oregon and Australian viticulture to New Zealand.

For orographic reasons and the fact that it is a peninsula in the Mediterranean, which mitigates the extremities, Italy has restructured viticulture from polyculture that, with 2,046,000 hectares, covered the whole territory, while specialised viticulture numbered 1,142,000 hectares, concentrating in the more suitable areas with favourable pedoclimatic factors.

The affirmation of the DOCs started in the peninsula after the Second World War, giving legal certainty and trading recognition to historically deep-rooted products (Chianti, Valpolicella, Barolo, etc., etc.)

The legislator was generous when defining the areas, which are like XXL clothes (see attached maps). In other words, the vineyards can find space in potential DOC areas to move both to high ground and to areas better suited to respond not only to climate change but also to consumer tastes.

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Figure 1. Location of the Marchesi de' Frescobaldi wineries in Tuscany indicated by a star.

It is certain that, from the Alps to the Strait of Sicily, there is an enormous variability within the pedoclimatic indices. We can find the same variability in the individual regions, as we will go on to demonstrate.

2. The ability of traditional grape varieties to adapt to climate change

Global climate change poses new challenges for plant species, including new and complex combinations of environmental conditions to which plants should adjust and adapt. The Mediterranean ecosystems are recognised elective places of biodiversity, but they are also hotspots for climate change due to the established action of several environmental variables. In the face of these changes, Mediterranean plants can migrate towards more suitable habitats, adapt through natural selection, adjust their phenotypic plasticity or die out.

The best-known vinegrowing regions in Italy have a long winemaking tradition and are considered to be of international importance. The adaptation of the wine grapevine to a warmer environment and reduced water is an important element for possible future cultivation in the context of sustainable vinegrowing practices. The wine grape varieties are traditionally grown in unique "terroirs" whose climate is a crucial component; the wine characteristics being directly linked to the climate of the region. A changing climate, therefore, is likely to modify both the style and the quality of the wine produced in a specific location.

The Italian peninsula has a vast range of elements linked to location which influence the performance of the vine. In fact, from a climatic point of view, Italy has an ample set of mesoclimates, ranging from dryer regions in the inland south, to the wetter regions in the northwest and northeast. Topography and soils are also very distinct throughout the peninsula, ranging from vast plains to steep mountainous regions, each with very different soil characteristics that may influence the spread and settlement of varieties. All of these elements are reflected in the different varieties grown throughout the peninsula.

To a certain extent, local varieties are an indirect manifestation of regional climate conditions. However, a multi-site study covering a vast range of different climates is needed to understand the heat requirements of varieties.

Furthermore, the concept of varietal plasticity should be considered, i.e. the ability to adapt to different climates [1,2]. Although heat requirements are specific to each variety [3–5], the same variety grown in different regions is able to show differences of up to 300 °C (Degrees-Day) in Italy.

Climate change is expected to lead Italian vinegrowing to new challenges, i.e. a remodelling of the best varietal zones. Future forecasts highlight global warming and long periods of water stress in Italy [6], accompanied by an increase in the frequency of extreme weather events [7]. Climate change may move the phenological stages forward [8–11].

The grapes will ripen with decidedly higher environmental temperatures than in the past [12,13], with negative consequences on wine quality, due to an imbalance of the organic components of the berry [14,15].

3. First case study: Tuscany

The Renaissance originated in Tuscany in the 14th century. During the same period, land was divided up into farms with sharecropping management.

The *Alberata* tree-trained vine landscape came about: the estate depended on the manor house, church or convent. The 16th century saw the refeudalization of the countryside with large estates, new nobles and new middle classes.

The sharecropping system strengthened and was particularly suitable to the hills.

The Lorraine period modernised agriculture (Academy of Georgofili) with crop rotation and field preparation in the hills (Cosimo Ridolfi).

The system continued until 1950–1970 with the decline of sharecropping and the difficulty for other forms of management. The "farm" system remained but transformed into an economic management with salaried workers, abandoning polyculture for specialised viticulture, with few medium-sized and large wineries (> 10 ha), 1,185 wineries cover 59% of the surface area.

The model winery considered (Marchesi Frescobaldi) concentrates on the historical focus described and is present in all the DOC vinegrowing areas in Tuscany, therefore it is a statistical sample that proves the theories supported in this study. (Table 1).

The geological origin and the pedological matrix affect all the variables: The Apuan Alps (Carrara marble), the Volterra badlands; Sienese sandstone and the Mount Amiata lava dome are an example of this.

The altitude and geographical position give Tuscany different phytoclimatic areas. In some wineries such as

Table 1. Vineyard surface area and Usable Agricultural Area (UAA) of the wineries owned by Marchesi Frescobaldi and their location [16] (for more statistical information: `www.devulpeetuva.com`).

VINEYARD SURFACE AREA AND USABLE AGRICULTURAL AREA OF THE Mdf WINERIES AND RELATIVE MUNICIPALITIES

MdF WINERY				MUNICIPALITY		1990			2000			2010		
	ha of vines	ha UAA	% UAA			ha of vines	UAA	% UAA	ha of vines	UAA	% UAA	ha of vines	UAA	% UAA
I COLLAZZI	25.7	101.6	25	Impruneta	FL	476	2,580	18	285	1,900	15	241	1,751	14
NIPOZZANO	318.9	408.1	78	Pelago	FL	351	1,541	23	412	1.329	31	552	1,471	38
CAMPERITI	65.3	96.1	68											
POMINO	98.2	127.0	77	Rufina	FL	261	1,247	21	290	1,450	20	287	923	31
REMOLE	11.6	95.5	12	Pontassieve	FL	845	5,145	16	728	4,282	17	485	3,382	14
CASTIGLIONI	165.1	325.0	51	Montespertoli	FL	2,009	7,833	26	1,975	7,315	27	2,047	6,376	32
CASTELGIOCONDO	274.0	340.3	81	Montalcino	SI	2,130	13,444	16	2,924	11,696	25	3,974	11,531	34
AMMIRAGLIA	143.5	180.8	79	Magliano in Toscana	GR	485	15,035	3	617	15,425	4	994	13,856	7
ORNELLAIA	131.9	146.6	90	Castagneto Carducci	LI	375	6,478	6	592	4,933	12	1,029	4,680	22
Vigneti di NUGOLA	96.1	101.2	95	Colle Salvetti	LI	206	4,120	5	111	4,269	3	66	4,292	2
CORTE	10.5	226.0	5	Borgo San Lorenzo	FL	134	5,690	2	110	5,500	2	60	5,000	27
	1,340.9	**2,148.1**	**62**			**7,272**	**63,113**	**12**	**8,044**	**58,100**	**14**	**9,735**	**53,262**	**18**
TUSCANY						70,900			58,170			59,839		
FRIULI : ATTEMS	32.2	35.5	91	Gorizia (Lucinico)	GO	291	1,164	25	264	644	41	306	588	52

Table 2. Altitude variation in the Tuscan wineries considered.

MORPHOMETRIC ZONING

MdF WINERY	MUNICIPALITY		MORPHOMETRIC INTENSITY	INTENSITY OF ELEVATION (m)				ALTITUDE (m)			SLOPE (degrees)			
				0 - 20	21 - 125	126 - 250	251 - 1000	< 201	201 - 600	>600	0 - 3	4 - 15	16 - 23	> 24
I COLLAZZI	Impruneta	FL	33.9		95.1	4.9		63.2	36.8		11.1	77.9	8.1	2.9
NIPOZZANO	Pelago	FL	53.1		27.0	61.3	11.7	13.5	53.7	32.8	6.5	63.6	18.5	11.4
POMINO	Rufina	FL	57.3		13.6	68.9	17.5	17.8	48.6	33.6	6.6	49.7	24.1	19.6
REMOLE	Pontassieve	FL	50.8		16.6	68.5	14.9	19.5	68.4	12.1	5.5	56.9	20.8	16.8
CASTIGLIONI	Montespertoli	FL	34.3	0.1	86.7	13.2		73.4	26.6		16.4	65.3	14.7	3.6
CASTELGIOCONDO	Montalcino	SI	33.9	1.6	74.9	23.1	0.3	28.9	70.2	0.9	21.0	64.1	11.5	3.5
L'AMMIRAGLIA	Magliano in Toscana	GR	27.8	3.8	86.8	8.8	0.6	79.6	20.4		32.2	55.3	10.4	2.1
ORNELLAIA	Castagneto Carducci	LI	23.3	37.9	36.5	24.2	1.3	77.4	22.6		50.7	29.6	11.9	7.8
NUGOLA	Collesalvetti	LI	18.7	39.5	49.1	11.2	0.1	91.0	9.0		52.4	35.7	9.0	3.0

Table 3. Variation of the bioclimatic indices of Huglin and Winkler in the Marchesi Frescobaldi wineries.

	HUGLIN									WINKLER								
	Ammiraglia	Attems	Castelgiocondo Carrione	Castelgiocondo Caselli	Castiglioni	Nipozzano	Nugola	Pomino	Remole	Ammiraglia	Attems	Castelgiocondo Carrione	Castelgiocondo Caselli	Castiglioni	Nipozzano	Nugola	Pomino	Remole
Storico	**2655**	**2247**	**2569**	**2425**	**2659**	**2343**	**2469**	**2017**	**2547**	**2141**	**1787**	**2060**	**1937**	**2135**	**1889**	**2035**	**1561**	**2006**
2011	2779		2615	2442	2591	2400	2479	2009	2643	2254		2034	1896	2057	1892	1994	1520	2022
2012	2676		2688	2572	2671	2457	2455	2021	2636	2193		2165	2060	2167	2026	2022	1583	2161
2013	2742		2458	2410	2626	2286	2461	2074	2313	2239		1978	1967	2090	1825	2058	1641	1821
2014	2460	2163	2388	2187	2557	2210	2358	1887	2510	1956	1721	1942	1753	2079	1813	1992	1474	1979
2015	2617	2332	2697	2517	2851	2365	2591	2095	2632	2065	1853	2180	2008	2282	1890	2110	1587	2047

Nipozzano, Pomino, Castelgiocondo and to a lesser extent Remole, the variations in altitude within the wineries may allow vinegrowing to be elevated, so it could benefit from lower degree days (Table 2).

Rainfall and temperature confirm what has been affirmed above, pointing out that Tuscan viticulture does not use irrigation, hence the variable of production volume is conditioned by rainfall.

The bioclimatic indices originating from different parameters considered, give a clear demonstration of the extreme variability of the different Tuscan areas (Table 3) with important differences particularly between Pomino (Rufina) and Castiglioni (Montespertoli).

The variation of the environmental characteristics observed throughout Tuscany protects from the danger of reducing viticulture due to ongoing climate change. In fact, due to the flexibility allowed by current production regulations that allow an elevation of viticulture also to high altitudes (500–600 m above sea level), the possibility of growing traditional Italian varieties will be safeguarded.

4. Second case study: Valpolicella

The description of vinegrowing methods in Valpolicella began in the Early Middle Ages when the term “terra cum vineis” was coined, indicating an area where vines where

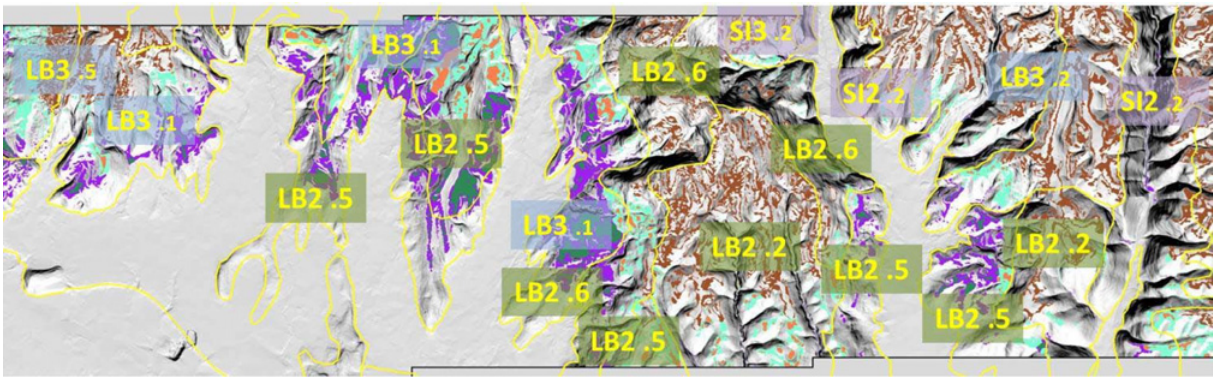

Figure 2. Classes of altitude-slope suitability on shaded relief of the elevation in the Valpolicella area under study and the main types of soil from the regional soil map.

grown: it could be made up of the "low vineyard", grown in the hills and the "high vineyard", grown in the plain.

The latter stood out for the type of support used, which could be a simple stake (dead support) or a plant (live support).

In around the 1400s, the "*piantata*" spread through the Verona plains"; rows of vines trained on live supports interspersed with cereal crops.

Abbot Bartolomeo Lorenzi wrote some important agronomical writings after his retreat to the house in Mazzurega, in Valpolicella, where he spoke, among other things, of choices of grape varieties, planting period, fertilizing, supports, green harvest and looking after the soil.

At the start of the 1800s, several academics at the Academy of Agriculture, Science, Letters and Arts in Verona devoted themselves to describing 80 varieties of red and white grapes grown in the province.

The use of the most important varieties in Valpolicella certainly has ancient origins. The Corvina and Corvinone varieties, coming under the varietal group generally called Corve or Corbe, had been used since ancient times. The name Corbina (or Corba) is mentioned by Prof. Domizio Cavazza in the volume "*Viticoltura*", which was part of the New Italian Agricultural Encyclopaedia (published by UTET, Turin, 1914).

For a few years now, vinegrowers in Valpolicella have chosen the highest altitudes to produce their grapes and wines.

The influence of the nearby Lake Garda is clear, especially the mild climate, but also the rise in average temperatures that often force early harvests.

For this reason, a study has been started to estimate how much vineyard surface area can be potentially invested in high hills, while taking into account some basic requirements for rational farming and for pedoclimatic characteristics in keeping with the production of the maximum possible quality.

5. Map databases used

During this study, the following digital map databases were used from the map archive of the Veneto region:

1. Regional DTM with cells of 5 metre sides in ASCII format, with map specifications relative to the sections of the CTR (Technical Regional Map) made by the CNR (National Research Council) in Pisa through the generation of the TIN, starting from contour lines and spot heights deduced by the CTRN.
2. Soil map of the Veneto, containing the soil typological units and the description of the map units in *shapefile* vector format.

Table 4. Values of the Winkler scale (GDD) per altitude-slope class of suitability – Valpolicella (average values for the years 2008–2009–2010–2011–2012).

slope / *altitude*	*0 –10%*	*10–20%*	*15–25%*
200–300 m	1958	2036	–
300–400 m	1875	1891	–
>400 m	–	–	1735

The values of the Winkler scale have been calculated according to the model provided by Boselli et al. [17], which is based on data processing on an orographic and topographic basis (altitude, relative position on the slope – distance from the bottom and the ridge – main exposure of the slope and size of the valley). Depending on the heat requirements of the Corvina variety (1800–1850 GDD), the highest areas may cause excessively late ripening with difficulty in reaching a sufficient potential alcohol content, especially in the more unfavourable vintages from a climate point of view.

The ability of the Corvinone variety to adapt seems to be better.

Figure 2 shows the various types of soil that characterise the upper Valpolicella and are compatible with quality viticulture:

LB1 = Soils on low ridges with a basaltic substratum and slopes modelled mainly in ledges and very anthropized.

LB2 = Soils on plateaus and long ridges with low slopes enclosed by steep, short escarpments, on limestone.

LB3 = Soils on plateaus and long ridges in calcareous marl (more rarely in hard limestone and dolomite rock) highly undulated with rounded forms.

SI2 = Soils on valley cuts and escarpments in hard limestone with moderately steep slopes.

SI3 = Soils on valley cuts, escarpments, small basins in calcareous marl (*Biancone*) with regular rounded steep slopes.

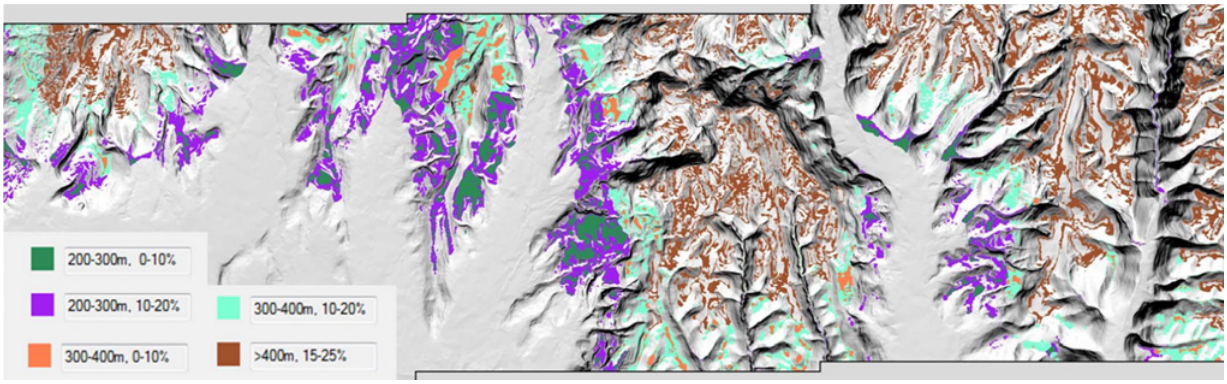

Figure 3. Classes of altitude-slope suitability specific for the variety on shaded relief of the Valpolicella area under study.

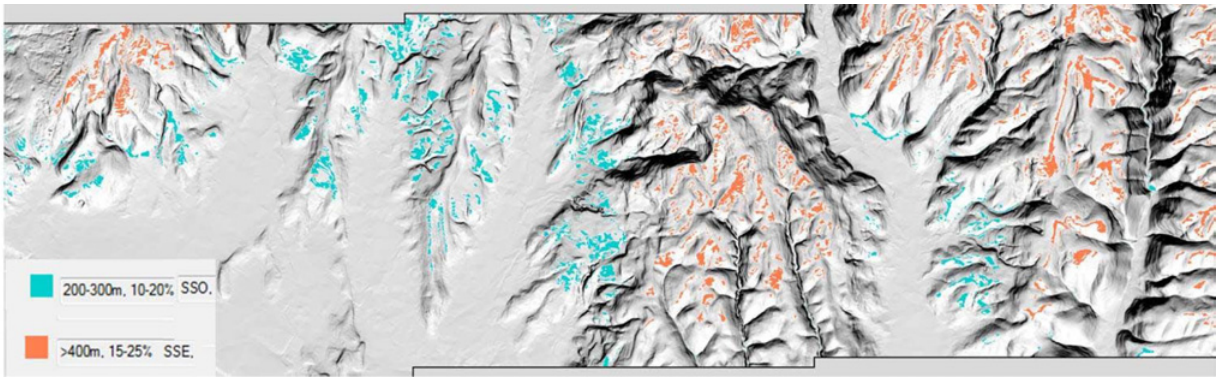

Figure 4. Classes of altitude-slope-exposure suitability specific for the variety on shaded relief of the elevation in the Valpolicella area under study.

These soils have very different characteristics but are all suitable to viticulture aimed at quality products. They are often highly calcareous soils, which limit vigour and productivity to favour maximum quality.

Figure 3 shows the different-coloured areas that could potentially be planted with vines. Particularly for the Corvina variety, if it is elevated to higher altitudes, it must be planted in the best exposures.

Considering the distribution of slopes of the altitude-slope classes in the Valpolicella area under study, the analysis of the two classes with most hectares (200–300m/10–20% and > 400m/15–25%) has been extended to the exposure of the slopes considering an optimum south/southwest exposure (aspect between 157° and 247°) for the 200–300m/10–20% class and south/southeast (aspect between 113° and 203°) for the >400m/15–25% class. Only considering the slopes with a south/southeast exposure, the number of hectares for the > 400m/15–25% altitude-slope class passes from 769 ha to 294 ha, whereas only considering the slopes facing south/southwest, the number of hectares of the 200–300 m/10–20% altitude-slope class drops from 535 ha to 219 ha.

6. Conclusions

Italian viticulture, according to the models tested, has the ability to adapt itself better than other countries to global warming, being able to vary cultivation altitudes up to high hills and mountains, setting off a mechanism called resilience. Moreover, the results indicate that Italian varieties have a higher capacity to adapt, because they have grown in a wide interval of heat conditions through time. The study has provided the basic knowledge needed to justify vinegrowing in those areas and has formulated the possibilities of extending viticulture from the current areas to other currently unused ones.

As well as providing a valid answer to climate change and increasing the intrinsic quality of the product, moving viticulture to hilly areas is a factor of primary importance for maintaining agroecological biodiversity, soil preservation and, above all, for tackling hydrogeological instability.

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