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Local Perceptions, Vulnerability and Adaptive Responses to Climate Change and Variability in a Winegrowing Region in Uruguay

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Abstract
Understanding climate variability in a winegrowing region is fundamental to understanding how its vineyards can adapt to climate change. For Uruguay, studying the vulnerability and adaptive responses of vineyards to climate change and climate variability is relevant due to its winegrowing region's economic importance and cultural heritage. Winegrowers and technical advisors were interviewed to evaluate their perceptions of climate change, vulnerability of their vineyards and how to adapt them. The main results showed that winegrowers had a clear perception of annual climate variability. The respondents highlighted the extreme climate events that had occurred over the previous few years and 71% of them believed that they had increased in frequency. Despite the perception of increase in climate variability in the region, they did not associate it with climate change. Overall, 43% of respondents agreed that changes in certain viticulture practices in recent years could have been due to climate change, especially those related to the preventive use of pesticides. The respondents identified climate risks that resulted in "bad" years for yield and quality (increase in extreme events (e.g., storms, hail), decrease in "cold" units in winter (i.e., temperatures <0 °C), increase in "hot" hours (i.e., >35 °C), increase in precipitation during the growing season and ripening period) as well as their impacts on vineyards. An adaptation matrix was developed from the viticulture practices that the winegrowers used in response to climate variability. Medium- and long-term adaptive responses to climate change can be based on the knowledge of winegrowers and their advisors.

Keywords Vulnerability · Adaptive measures · Grapevine · Vineyards · Climate Variability · South America

Introduction

Identifying agroecosystems (i.e., units of agricultural production) that can adapt to the environment, particularly to climate variability, has been a goal of humanity throughout history. In recent decades, the potential impacts of climate change have led to more specific studies of crop adaptation.

Grapevine, as a climate indicator plant (Chuine et al. 2004), has been studied in several regions. Studies of grapevine adaptation can be applied to other perennial production systems; however, the vulnerability of systems varies considerably among locations.

For Uruguay, studying grapevine vulnerability to climate change and variability is relevant due to its winegrowing region's economic importance and cultural heritage. Grapevine has been cultivated in Uruguay since the arrival of the first Spanish and Portuguese inhabitants in the 16th century. The first commercial vineyards were established around 1870. They included the red-wine cultivar Tannat, which was planted by Basque and Italian immigrants, who also introduced the habit of wine consumption, which reached actually more than 30 l/person/year, along with the consumption of 98 kg of meat/person/year. Vineyards in Uruguay cover 7000 ha, 91% of which produce red and rosé wines and 85% of the vineyards have <5 ha and often are managed by sixth-generation winegrowers. Viticulture generates 30,000 jobs directly and indirectly (i.e., 2.5% of Uruguay's working population). Wines of the Tannat

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cultivar have been marketed since the 2000s and have conquered more than 46 international markets due to their typicity.

Uruguay has a climate suitable for growing grapevine (Ferrer 2007). Its main winegrowing region, in the south has a warm, temperate oceanic climate, and relatively high precipitation (i.e., 1100 mm/year) (INIA 2020). Production in the region like that at the national level, varies greatly among the years (Fig. 1), in part due to interannual climate variation (Fig. 2).

The International Panel on Climate Change defined agroecosystem vulnerability to climate change as the sum of its physical exposure, sensitivity and adaptive capacity (i.e., the impact of the exposure or threat) (IPCC 2007). Physical exposure refers to the often-adverse climatic conditions that an agroecosystem endures, such as temperatures that decrease crop development and growth, deficient or excessive precipitation, and high winds. Grapevine is a perennial crop (>30 years of production) whose annual growing cycle in the Southern Hemisphere begins with bud break in September, and ends when its leaves fall in April. It remains dormant in winter (May–August). The optimum temperatures for grapevine vary throughout the growing season, with 25 °C the optimum for photosynthesis (Champagnol 1984; Hunter and Bonnardot 2011). Similarly, optimum precipitation for plant growth and development during the growing season range from 500 to 750 mm (Jackson 2008).

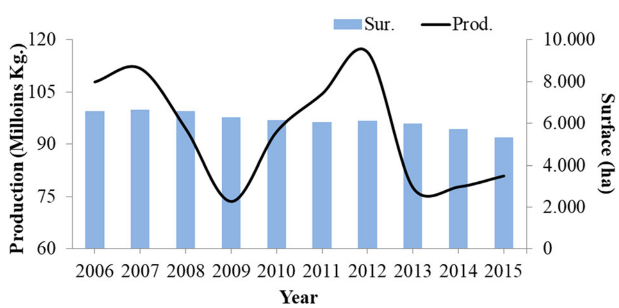

Fig. 1 Total production (millions of kg) and area (ha) of vineyards in the departments of Canelones and Montevideo, Uruguay, from 2006 to 2015 (INAVI 2019)

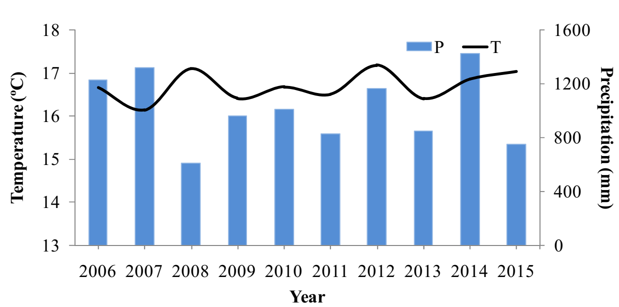

Fig. 2 Mean annual temperature (°C) and annual precipitation (mm) in INIA Las Brujas, Canelones, Uruguay, from 2006 to 2015 (INIA 2020)

Grapevine vulnerability was based on adverse physical exposure: extreme temperatures (e.g., heat waves with temperatures above 35 °C, cold snaps with temperatures below 0 °C), precipitation deficit (water stress during grape ripening), extreme precipitation, direct solar radiation (Bálo et al. 1986; Schultz 2000; Van Leeuwen and Vivin 2008), or combinations (Spayd et al. 2002; Goto-Yamamoto et al. 2008). An agroecosystem's sensitivity is based on the impact of certain environmental conditions. Several studies have analyzed the sensitivity of grapevine to climate variables (Barbeau et al. 2014). Sensitivity is determined via growth and development indicators (e.g., phenological states), production and the quality of grapes and wine. Grapevine's plasticity (i.e., ability to change in response to stimuli or inputs from the environment; West-Eberhard 2008) is well known. Sadras et al. (2009) measured the phenotypic plasticity of three crops (wheat, barley, and grapevine), according to productivity and phenology, and confirmed that grapevine had high phenotypic plasticity.

The adaptive capacity of an agroecosystem includes the producers' ability to address physical exposure as a threat. It entails mainly the human component and depends on several factors, such as the producer's nature (family or business), ability to learn, access to resources, and knowledge of the crop (Grothmann and Patt 2005; Yaro 2013). According to Van Leeuwen et al. (2013), winegrowers's ability to adapt management practices has mitigated the impacts of climate change on grapevines.

The adaptive capacity of an agroecosystem also includes producers and technical advisors' perceptions of climate change in the production sector (Grothmann and Patt 2005). At the global scale, perceiving climate change as a risk could help adapt effectively to climate change and variability (Battaglini et al. 2009; Yaro 2013). At the local scale, winegrowers' perceptions of spatial climate variability are essential to adapt vineyard management to local situations, for example by delaying pruning in plots in which late frost is a risk (September or October). Goulet and Morlat (2011) demonstrate the importance of performing interviews to learn about winegrowers' savoir-faire to assess adaptations of their viticulture practices and vineyard management.

As Kelly and Adger (2000) indicate, it is not sufficient to consider adapting in the future, when the climate will have changed, because it is already changing and must be studied. Neethling et al. (2016) studied changes in practices as adaptive responses to the climate change in two winegrowing regions in France (Anjou and Saumur). They identified several levels of adaptive response, from reactive to anticipatory tactical strategies, in these regions. Winegrowers in these regions have much less freedom to adapt management practices (due to the national regulation of the *appellations d'origine controlée* AOCs) than those in Uruguay, where the production or quality of grapes and wine are not regulated (except for the minimum alcohol content).

Lereboullet et al. (2013) studied specific adaptive responses of winegrowers in France (a traditional country) and Australia (the "New World"). Australia was considered to have a more resilient system since its production regulations are more liberal, traditions are weaker and effective collective actions exist that support major changes at large scales (e.g., water recycling systems, alternating cultivars).

Sensitivity and vulnerability matrices are used in climate change studies to assess impacts and organize responses. Corbon et al. (2009) used risk matrices to study grasslands in Australia. In a matrix of the consequences of climate change and variability, they demonstrated that risk increases as the probability of occurrence becomes more certain.

A risk matrix can help identify, prioritize, and manage risk at multiple levels (e.g., business, industrial, sectoral, national). The dynamics of vulnerability must also be considered. According to Belliveau et al. (2006), a system's vulnerability to a threat and resulting adaptive response to it may make the system more vulnerable to other stress factors.

An overall vision of exposures of grapevine characteristics (e.g., yield, grape composition, health) to multiple threats helps establish different levels of vulnerability and thus different responses.

This study was based on four hypotheses: (1) winegrowers in the region understand local climate variability, (2) management practices over the past 20 years have changed in part due to local and temporal climate variability in the vineyards, (3) changes in practices may help determine the vulnerability of winegrowing systems to local and regional climate variability, and (4) local knowledge may help identify suitable adaptive responses to climate change and climate variability. Our objectives were to identify winegrowers' perceptions of climate variability in southern Uruguay, develop matrices to organize information about vineyard vulnerability, and describe adaptive responses to climate change and climate variability. From this perspective, medium- and long-term adaptive responses to climate change can be based on the knowledge of winegrowers and their advisors (Boissière et al. 2013).

Materials And Methods

The study was performed in the main wine-growing region in Uruguay, in the departments of Canelones and Montevideo. The region contains 4862 ha of vineyards, which represents 77% of vineyard area and 88% of wine production in Uruguay (INAVI 2019).

The method used consisted of two steps: (1) develop and perform interviews to evaluate the perception and adaptive capacity of winegrowers to climate change and climate variability and (2) analyze data by developing matrices (i.e., vulnerability matrix and adaptive matrix) of vineyards in southern Uruguay, according to the risks climate variables identified by the winegrowers.

Evaluation of Perception and Adaptive Capacity. Development and Performance of Interviews

To study dynamics of viticulture practices in the context of climate change in the winegrowing region of southern Uruguay, the study consisted of semi-directed interviews with major stakeholders in the sector (38 winegrowers and 3 technical advisors from the region). The face-to-face interviews were performed in winters (July and August) of 2014 and 2016, since winter is the season with the least vineyard activity. Winegrowers were selected for being known in the sector for their industry experience and to include vineyards of different sizes (Table 1). The winegrowers interviewed owned the vineyards and the types of wine they produce varied (high-quality wines and/or table wine). They represented 19.6% of the 193 wineries in the region (INAVI 2019). The technical advisors interviewed worked in the region and had a long history in individual private consulting and involvement with winegrowers groups.

All respondents agreed to participate and received no incentives for doing so. The purpose and objectives of the study were explained before beginning the interviews. The interviews were audio recorded with the respondents' permission (without revealing names). Each interview lasted in an average of 1 h and 32 min. The answers were transcribed by one person and analyzed by identifying of the words used most often. The protocol for the interview questions is available in Supplementary Materials.

To test the hypothesis that winegrowers understood local climate variability, we asked respondents to describe the climate components they perceived as most relevant to their vineyards. The interviews provided information

Table 1 Description characterization of the winegrowers' interviewed

Variable	Group	Number of cases	Percentage (%)
Surface area	<10 ha	2	5.3
	Between 10 and 20 ha	16	42.1
	Up to 20 ha	20	52.6
Years of experience	<20 years	2	5.3
	Up to 20 years	36	94.7

Table 2 Annual and perennial vineyard practices described during the interviews

Term of the practice	Type of vineyard practice	Detailed practices
Annual	Canopy management	Canopy clearing
		Leaf removal
		Rootling
	Yield management	Pruning
		Thinning
	Soil management	Management of spontaneous vegetation
		Use of herbicides
		Fertilization
	Phytosanitary management	Type of management
		Use of specific phytosanitary products
	Harvest management	Type of harvest
		Enological practices
Perennial	Implantation	Topography
		Planting density
		Row orientation
		Trellis system
	Planning	Irrigation system
		Frost control
		Weather insurance
	Choice of cultivar and rootstock	

about annual and perennial vineyard practices (Table 2). The respondents were asked about changes in their vineyard practices in recent years and the factors that influenced these change (e.g., whether the criterion for winter pruning had changed and if so, which factor had influenced this change).

Respondents were then asked to classify how suitable vintages from 2000 to 2014 had been for winemaking (i.e., "very good", "good", "bad", "very bad") and the factors that had influenced this classification. Finally, their perception of climate variability and climate change was assessed via questions about the changes in and frequency of extreme climatic events and the impacts on grapevine.

Data Analysis

Development of vulnerability matrices

To determine the vulnerability of viticulture systems in the region, matrices were developed by modifying the matrix system of Corbon et al. (2009) for regional climate threats that respondents identified as having the greatest impact on the grapevine. According to Corbon et al. (2009), it is necessary to consider the climate threats (which determine physical exposure) and factors (which determine sensitivity) that affect crops the most. Common climate risks were identified from the interviews. We asked the respondents to define five climate factors that generally cause low wine quality and "bad" or "very bad" production years.

We considered five key factors of grapevine growth and development that are sensitive to climate: yield (final grape production), phenology (plant development), final grape composition separated into primary compounds (sugars, acidity and pH) and secondary compounds (phenolic compounds and aromas), and health status (disease and pest pressures). Based on their experience and local observations, each respondent was asked to relate the five climate threats to the grapevine factors.

Vineyard vulnerability was assessed by determining negative consequences of each threat to the grapevine. Three levels of negative consequences were identified and then represented by different colors in the matrix: low consequences (pale pink color), medium consequences (yellow color), and high negative consequences (orange color).

Development of local adaptative responses to climate variability in the region

Local adaptations to climate variability resulted from the perceptions and vulnerability of viticulture systems in the winegrowing region of southern Uruguay. The respondents, who used their savoir-faire to make decisions about daily management practices, considered these measures. The measures were shown in an adaptive matrix, using the method of Corbon et al. (2009), and were represented as three levels of adaptive capacity, referenced by different colors in the matrix: high (pale pink), medium (yellow), and low (orange). Adaptive capacity is the ability of an entity (winegrowers in our study) to adjust to potential damage, use opportunities or act in response to the impacts of climate change (IPCC 2007).

The measures represented different adaptive responses that corresponded to the horizon over which the winegrowers considered the practice. The adaptive matrix showed three levels of adaptive responses were referenced with different colors within the matrix: tactical reactive (pale pink), tactical anticipatory (yellow), and strategic anticipatory (orange). Adaptive measures were identified according to the time of action (reactive or anticipatory), and their duration (tactical or strategic) (Belliveau et al. 2006; Neethling et al. 2016). Strategic anticipatory measures with low adaptive capacity were represented in brown color in the matrix.

Results

Influence of Climate on Decision Making and Wine Quality

Winegrowers' perception of local climate variability

When we tested the hypothesis winegrowers understood local climate variability, respondents described in particular their perception of interannual variations (interannual variability). One respondent mentioned "each vintage year differs from the others". For climate variability, 71% of the respondents perceived an increase in the frequency of extreme events in recent years, such as precipitation, with strong winds or hailstorms. The winegrowers recognized local climate variability, but did not always describe it as "climate change".

When asked to classify the suitability of vintages (from 2000 to 2014) for winemaking, respondents classified 2000, 2002, 2004, and 2011 as "very good" years due to a complete ripening period and little precipitation in summer (Table 3). Respondents classified 2001, 2005, 2012, and 2014 as "very bad" years. The "bad" and "very bad" years indicated adverse climatic conditions throughout the entire growing season, especially during ripening (excessive precipitation in the month before harvest). As a result, climate had a major influence on irregular harvests with losses of yield and quality. All respondents attributed these irregular harvests to the climate. The years with some extreme events (e.g., 2013, with hail) were classified as "good" or "bad" depending on the extent of damage within the region.

Table 3 Respondents' classification of the suitability of vintages classification from 2000 to 2014 for wine making and the influencing factors

Class	Vintage	Characteristics
Very good	2000 2002 2004 2011	Full maturation. Scarce rainfall during ripening Strong water stress during the ripening period in some cases (ripening blockage) (in 2011)
Good	2006 2009 2013	Good for vineyards with no hail damage (in 2013)
Neutral	2010	
Bad	2003 2008	Limited budding due to a late spring frost (in 2003) Rainfall at the end of the cycle (in 2008)
Very bad	2001 2005 2012 2014	Several sanitary problems due to the rainfall during the ripening period (rotten grapes)

Changes in viticulture management practices

Winegrowers had modified canopy management (canopy clearing, leaf removal, and rootling) practices in recent years and 71% of respondents identified leaf removal as an important practice to perform throughout the entire vineyard. The practice requires long-term dedication from staff, who may be, specifically trained for it. The clearest changes in leaf removal over the past 20 years included prioritizing which plots to clear, the intensity required to achieve plant balance and the type of technique (using specialized personnel or machines). Another factor that changed was the grape quality (health) achieved as a function of the cost of leaf removal. Manual leaf removal often requires 3 months of staff work, has low efficiency and does not result in better grape quality than mechanized leaf removal.

All respondents indicated that soil management practices had changed the most over the previous 20 years. To analyze this, the respondents considered a longer period (since 1990) to describe the most intensive tillage. At the beginning of the 1990s, the soil was deeply tilled throughout the year to remove weeds. Subsequently, tillage shifted from high intensity to minimum tillage, in which tillage was first performed in the row and then (in 2002) between rows. The impact of tillage on soil properties was the greatest impetus for this change, since serious compaction and erosion problems that restricted root development had been observed. Beginning in 1995, vegetation cover was left in the row and between rows. Between rows, spontaneous vegetation or grass was left, depending on the destination of production and type of vineyard. In comparison, conservation od biodiversity began to be important only in 2000.

Some winegrowers mentioned changing the driving system in recent years. The Vineyard Reconversion Plan of Uruguay's Ministry of Agriculture, Livestock and Fisheries (MGAP in Spanish) encouraged production of high-quality wines and provide a package of technical measures (implemented from 2001 to 2003). One of them, the lyre trellis system was promoted to produce high-quality wine, since it could increase photosynthetic efficiency and grape load per plant without losing quality standards (Ferrer 2007). However, the trellis system requires many operations of the grapevine canopy to achieve final ripening. The lack of technical adjustments, high cost of labor, and the inability to mechanize the vineyard caused winegrowers to "return" to the standard trellis system (i.e., vertical shoot positioned).

The respondents highlighted changes in pesticide treatments. Awareness of treatments with preventive and specific objectives for particular diseases (e.g., rot due to *Botrytis* spp.) has developed, in part due to the changes in the chemical composition of the active ingredients, as well as the role of the MGAP in implementing Integrated

Production Standards. Currently, pesticide management aims for preventive disease control before precipitation, using specific products for bunch rot (87.5% of respondents), non-application of insecticides (except for specific infections), and more effective treatments with adequate volumes of water and active ingredients depending on the trellis systems, and theus leaf area to treat. For the latter, winegrowers mentioned the importance of technical advice for managing diseases and pests.

Overall, 43% of respondents agreed that climate could have influenced the change in practices, especially those concerning the preventive use of pesticides. Although all respondents attributed the production results to climate when classifying the vintages, they did not perceive management practices as adaptations to climate change.

Vulnerability of the vineyards and local adaptive responses to climate variability

The interviews revealed external climate threats in the region that influence grapevine characteristics and that were perceived as risks when producing grapes for wine. Respondents indicated that these climate threats caused defined as the "bad" years and included an increase in extreme events (e.g., storms, hail), a decrease in the number of cold hours (less accumulation of cold in winter), an increase in the number of days with temperatures above 35 °C (which stop grapevine photosynthesis), an increase in precipitation intensity during the growing season, and an increase in summer precipitation (which decreases grape ripening and health). The negative consequences of these threats to the vineyards were identified in the vulnerability matrix (Fig. 3). The respondents indicated that excess precipitation had the most negative consequences for the vineyards.

For all the respondents, climate threats influenced yield, phenology, grape health at harvest and especially final grape composition. Respondents cited a direct effect of extreme precipitation on wine quality (e.g., decrease in aromas, final color, loss of sugar). Respondents could not identify potential negative consequences of mild winters or extremely hot summers on grapevine or grape health.

Adaptive measures that winegrowers and advisors used or recommended were summarized in the adaptive matrix (Fig. 4). Tactical measures were strongly associated with yield (Fig. 4). For the respondents, the negative impact of climate on final yield could be mitigated easily by their high capacity to manage their vineyards (e.g., leaf removal, grape thinning).

Respondents did not distinguish adaptive measures to reduce the vulnerability of the final grape composition according to the type of compound (primary or secondary), because none were found for basic compounds and polyphenols. All respondents indicated that winery technology was essential for them to modify the initial amount of must in higher-quality wines.

The distribution of vineyards in the region emerged as a crucial element in reducing vulnerability: 67% of the winegrowers owned vineyards in multiple locations in the region and have been enthusiastic about its benefits for reducing climate risks.

Risk variables perceived	Yield	Phenology	Berry composition (primary compounds)	Berry Composition (secondary compounds)	Pests and diseases pressure
1. Increase in extreme events	Direct yield lost due to grape damages and indirect lost due to foliar area damages	Cycle delay due to foliar damage causing other points of growth	Problems in accumulation and synthesis of compounds. Low content of soluble solids (SS)	Decrease in aromas and color	Increase in incidence and severity of diseases in broken skin grapes
2. Decrease in cold units during winter	Decrease reproductive differentiation - Nº flowers - Nº grapes	Budbreak heterogeneity	Maturation heterogeneity	Maturation heterogeneity	No references of vulnerability
3. Increase in hours with temperatures above 35ºC	Decrease berry size due to dehydration	Could advance and/or shorten phases and maturation	SS increase and acidity decrease. Severe water stress causes ripening blockage	Increase polyphenols synthesis if ripening blockage does not occur	No references of vulnerability
4. Increase in precipitation during the vegetative cycle	Decrease in yield due to fruitset problems if precipitations occur during flowering	Stimulate vegetative growth could delay phenological phases. Spring rainfall impact flowering and fruitset	SS dilution. Unbalance of primary compounds	Decrease in aromas and color	Increase in incidence and severity of diseases that impact in leaves and grapes
5. Increase in precipitation during the ripening period	Increase in yield due to berry hydration	Stimulate vegetative growth could delay phenological phases as maturation	SS dilution. Unbalance of primary compounds	Decrease in aromas and color	Increase in incidence and severity of diseases in broken skin grapes

Negative Consecuences
Low
Medium
High

Fig. 3 Vulnerability matrix of vineyards in southern Uruguay based on winegrowers' perception of risks

Risk Variables perceived	Yield	Phenology	Berry composition	Pests and diseases pressure
1. Increase in extreme events	Avoid severe defoliation that does not affect the load	Avoid severe defoliation	Vinification management, e.g. chaptalization when grapes are inadequately ripened	Adapt preventive management of diseases to decrease sanitary pressure
	Establish vineyards in different locations within the wine region			
2. Decrease in cold units during winter	Use of chemicals to advance/homogenize budbreak and increase Nº shoot/plant	Time of pruning. Use of chemicals to advance/homogenize budbreak	Vinification management, e.g. chaptalization when grapes are inadequately ripened	Adapt preventive management of diseases to decrease sanitary pressure
3. Increase in hours with temperatures above 35ºC	Canopy management (defoliation and rognage) to decrease foliar area	Avoid severe defoliation in white varieties	Night harvest to avoid compound degradation and vinification management. Improve transport system to the winery	Adapt preventive management avoiding extreme temperatures during the treatments
	Establish vineyards near the sea with temperate temperatures			
4. Increase in precipitation during the vegetative cycle	Grape thinning to favor adequate ripening (decreasing pit force)	Change to rootstocks more tolerant to root asphyxia or less vigorous	Favor adequate leaf area to improve ripening	Adapt preventive management of diseases to decrease sanitary pressure and decrease the number of treatments
	Establish vineyards in different locations within the wine region to diversify soil type and depth			
5. Increase in precipitation during the ripening period	Grape thinning to favor adequate ripening (decreasing pit force)	Change to rootstock more tolerant to root asphyxia. Change to varieties with early maturation to avoid rainfall	Vinification management, e.g. chaptalization when grapes are inadequately ripened	Adapt preventive management of diseases to decrease sanitary pressure
	Establish vineyards in different locations within the wine region could minimize risks due to strong spatial variability of precipitation			

Adaptive Capacity

Adaptive Responses	High	Moderate	Low
Tactical Reactive			
Tactical Anticipatory			
Strategic Anticipatory			

Fig. 4 Adaptive matrix of vineyards in southern Uruguay

In the medium and long term, adaptive measures included vineyard systematization, especially the selection of cultivars and production objectives. In this sense, winegrowers did not want to risk producing a single cultivar, since they could lose all production under adverse conditions. This approach is typical for winegrowers of Tannat, which is an emblematic cultivar for high-quality wines. They preferred to grow another cultivar (e.g., Merlot) in some of their plots to avoid losing grapes to rot. Winegrowers who had less diverse, mono-cultivar suggested managing table-cultivars as a way to reduce the risk of losing grapes grown for a particular type of wine. Like the previous measure, diversifying the quality of grapes reduces the risks to the winery.

Discussion

The Influence of Climate on Decision Making and Final Wine Quality

The interviews revealed that vineyards in the region were sensitive to climate, but that climate had less influence on decision making than the market, institutional arrangements, and labor availability. Annual practices that did not involve controlling diseases or pests in the vineyard (e.g., soil management, canopy management) changed based on production criteria (e.g., load control) and quality (e.g., change in standards for final grape composition), availability (and cost-benefit ratio) of labor and consumer demands (e.g., change or improvement in the final product). Hadarits et al. (2010) obtained similar results in the Maule region in Chile. In the present study, winegrowers' management strategies during the growing season were based on labor availability and the markets and adapting their practices to climate change was not a priority. Many winegrowers attributed this to the lack of reliability of weather forecasts, which often announce torrential downpours that end up delivering only a few mm of precipitation, or extreme weather events that occur without weather alerts (e.g., hail in January 2013). As Yaro (2013) observed, non-climate factors had the most influence on winegrowers' adaptations to climate change and variability. Nonetheless, the classification of "good" and "bad" years highlighted the importance of climate, especially unfavorable conditions during ripening, on the final grape quality.

Several studies agree on the influence of climate on the quality of vintages. Jones and Davis (2000) analyzed the influence of interannual variability on the final price of wine in Bordeaux, France. In their study, 62% of total variance in the quality rating was due to four climate variables: duration of insolation, number of days with temperatures above 30 °C between flowering and veraison, number of days with temperatures above 30 °C during veraison and precipitation during ripening. In the same region, Baciocco et al. (2014) determined that climate had a fundamental influence on wine quality, since mean maximum temperature during the growing season could distinguish most "good" and "bad" vintages of sweet white wines and red wines.

The analysis of vineyard management during "good" and "bad" years helps determine management measures related more to climate risks than to other risks (e.g., economic, marketing, social) (Belliveau et al. 2006). Since viticulture systems are vulnerable to several risks, winegrowers' who adapt management practices in response to interannual climate variability may also address climate change risks.

Perception, Vulnerability of the Vineyards and Local Adaptive Responses to Climate Variability

Boissière et al. 2013 defined "local perceptions" as the way in which individuals identify and interpret observations and concepts. While climate change may create conditions that differ from previous experience, local knowledge, and perception remain the foundation of any local response. The perception of climate change varied in the interviews. Despite knowing about climate change from the scientific community in Uruguay, the winegrowers in the region responded with skepticism about climate change. Most family winegrowers had the strongest perception of climate variability, while larger winegrowers were more skeptical about the impacts of climate change. According to Yaro (2013), small producers perceived local impacts of climate change because they relate them to characteristics such as productivity; even if larger producers understood the science of the climate change better.

Interviews indicated that external threats not related to the climate influenced vineyard vulnerability, such as labor cost, the final price of grapes, and restrictions on selling wine in stock in the winery. Several studies have demonstrated that climate and non-climate factors make viticulture systems vulnerable (Belliveau et al. 2006; Hadarits et al. 2010; Pérez-Catalá 2013). As in the present study, Füssel (2010) determined that these non-climate factors are external factors of the system that influence in biophysical and social vulnerability.

Vineyard adaptive responses to the climate threats identified by winegrowers and advisors are applied over different horizons. In the short-term, the measures address daily climate variability; some are anticipatory (Belliveau et al. 2006), such as irrigating the vineyard to reduce thermal stress during summer and avoid restricting ripening (Flexas et al. 2010), while others are reactive, such as applying hydrogen cyanamide to homogenize bud break during mild winters (i.e., low accumulation of cold hours) (Martin and Dunn 2000).

Long-term strategic adaptations can be anticipatory, such as choosing rootstocks that are more resistant to root asphyxiation and thus to excess soil water (Koundouras et al. 2008). Another option is to choose other growing sites, such as those at higher elevations, to avoid frost damage at sites susceptible to frost. As Belliveau et al. (2006) argue, climate is not the only factor used to select cultivars; thus, cultivar selection is not an adaptive response to climate change only, but a response to competitiveness on national and/or international markets.

A measure is considered strategic reactive when an opportunity occurs in a given year, such as when "good" end-of-fiscal-year finances allow winegrowers to invest in the system to reduce risks (Belliveau et al. 2006). Changing the trellis system to metal poles, is an example given in the adaptation matrix, resists the wind better that concrete poles. Another example is the potential to buy better pesticide-application equipment (i.e., atomizers) to optimize pesticide use and thus improve vineyard health.

Extreme weather events in the region are a clear example of the benefit of owing vineyards in multiple locations. Hail in January 2013 damaged several vineyards there but did not greatly decrease the income of all winegrowers because their other vineyards were not damaged. Similarly, events with high spatial variability, such as storms, can decrease the final grape quality greatly when they occur close to technological maturity. One winegrower said: "While one plot of Tannat suffers from excess water, another plot 3 km away may be suffering from water stress".

In the medium and long terms, adaptive measures also include vineyard systematization, especially the selection of cultivars and production objectives. In this sense, winegrowers did not want to risk producing a single cultivar, since they may lose all production under adverse conditions. Diversifying the quality of grapes also reduces the risks to the winery.

One way to reduce vulnerability when adaptive capacity is low, which the adaptation matrix did not cover, is for winegrowers to form groups. In the sample 21% of the winegrowers belonged to groups (called CREA) that provide technical advice, information exchange, and sharing of vineyard machinery. Sharing of machinery is relevant and increasingly used in the region, since many winegrowers are concerned about increasing costs of the labor force and the lack of adaptation to mechanize systems in their vineyards (e.g., the lyre trellis system). They emphasize the need to improve the mechanized management system to adopt it appropriately in their vineyards, while respecting the schedule of activities (e.g., leaf removal) and the budget.

Conclusions

Winegrowers in southern Uruguay have specific criteria for decision making in vineyard management that is part of local knowledge. These criteria have changed over time due to the need to modify grape quality, control plant balance, and meet consumer demands for specific wines. However, climate rarely influences decision making during the growing season or, to a lesser extent, medium-term decisions, such as choosing which cultivars to plant. Nonetheless, winegrowers understand interannual climate variability, as well as the influence of climate on the quality of wine in specific years.

The winegrowers have little perception of climate change and assume that it is a future and long-term issue. Although they are sensitive to interannual climate variability, many do not attribute this variability to climate change. This may be due to less local communication about impacts in the region or their causes (e.g., increase in climate variability, ENSO phenomena), than that at the international level (e.g., Northern Hemisphere), such as temperature increases and more extreme and prolonged droughts.

The matrix method provides clear and concise adaptive responses to specific climate in the region, which stakeholders perceive as a risk to producing high-quality grapes. Short-term tactical adaptive measures refer to the source/sink balance of the grapevine to achieve a final grape composition suitable for producing fine wines. Strategic adaptive measures in the medium and long term include the systematization of vineyards, selection of cultivars and rootstocks, and ownership of vineyards in multiple locations in the same region.

This study provides practical management practices for climate threats perceived by stakeholders in the region.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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