Influence of Weather and Climatic Conditions on the Viticultural Production in Croatia

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Abstract

Viticulture is strongly influenced by weather and climate conditions. The aim of this research is to increase the adaptability and reduce the vulnerability of Croatian viticulture related to the impact of climate change on grape and wine production through the revision wine growing zones in Croatia (analysis of existing zones and possible proposal of the new ones). Data from the 79 meteorological stations of the Croatian Meteorological and Hydrological Service (DHMZ) were used for calculations of the Huglin Index (HI), for the period 1961–2018. In the last 30 years. HI increased by 200–300°C compared to the reference period 1961–1990. The research also includes the impact of temperature conditions on the harvest date and vine grape quality (sugar content and total acidity) through monitoring of four cultivars (Chardonnay, Graševina, Merlot and Plavac mali) for the period 2001–2018. Uvometric data for the considered cultivars have been analyzed in 2017 and 2018. Significant changes in distribution of wine growing zones and extension of suitable areas for grapevine cultivation to areas with higher elevation was detected. Significant effect of increased temperatures on earlier harvest dates, increased sugar content and reduced total acidity was observed.

Introduction

In the last few decades, climate change has had an increasing economic and social impact on a global scale. Since solar radiation, precipitation, air and soil temperature and humidity are factors that control plant growth and reproduction, changes in few of these meteorological elements can lead to changes in the vegetation distribution. The use of grapevines as an effective indicator of climate change is justified by the high sensitivity of this culture to climate variation, meaning that climate change could lead to serious consequences and great economic damage in the wine sector (Ollat, Van Leeuwen, Garcia De Cortazar Atauri, & Touzard, 2017). Due to the increasing number of extremely warm years, future climate scenarios predict that areas suitable for

growing vines will move towards the northern areas, and the southern regions will be too hot and therefore will no longer be suitable for growing certain cultivars (Lazoglou, Anagnostopoulou, & Koundouras, 2018). Viticulture and winemaking are important industries in Croatia. According to the data of the Paying Agency for Agriculture, Fisheries and Rural Development (PAAFRD) for 2021, 34,647 agricultural holdings in Croatia were engaged in viticultural production on a total of 18,126.26 ha. There is a lot of evidence that Croatia is sensitive to climate change, as it is located in a sensitive area of Europe, as a transition zone between Central Europe and the Mediterranean, where the trend of rising average annual air temperature has become particularly pronounced in the last 25 years (Zaninović et al., 2008). In recent years, Croatia also observed great variability in the extreme amount of precipitation from droughts to major floods (Cindrić, Telišman Prtenjak, Herceg-Bulić, Mihajlović, & Pasarić, 2016).
In Croatia, the division of wine-growing zones is related to the first regionalization of wine-growing areas in the 1970s. Proper definition of wine-growing zone is crucial for current production as well as for future development. It is necessary to determine the boundaries of individual zones, to make their detailed characterization in terms of climatic conditions and soil properties, as well as the range and methods of viticultural production Due to climate change, changes in the technology of grapevine cultivation and wine production, as well as changes in the assortment, continuous work is needed on zoning and characterization of individual wine regions. Given that the current Croatian wine-growing zones are based on data and methodology from almost 50 years ago, it is necessary to revise them.

Materials and methods

Meteorological data were collected from 79 synoptic and climatological stations of the DHMZ. Data from the mean, maximum and minimum daily air temperatures, from the period 1961–2018 were used. Two sets of data were used to calculate agroclimatic indices. The first refers to the period 1961–1990, and the second to the period 1989-2018.
Four grapevine cultivars were selected for the research. Graševina and Chardonnay for white cultivars and Plavac mali and Merlot for red cultivars. In 57 reference vineyards during 2017 and 2018, growth development and chemical composition of grapes of these cultivars were monitored. Graševina as the most represented vine cultivar in Croatia covers 25% of total vineyards, while Plavac mali as the third cultivar in terms of total representation, i.e., as the most represented red cultivar, covers 8% of the total vineyards in Croatia. Cultivars Chardonnay and Merlot are taken as examples of international varieties that are represented in all wine-growing regions of Croatia due to their pronounced ecological adaptability. In addition, Merlot in fourth place with 5% and Chardonnay in sixth place with 4% of the total area planted, are among the 20 leading grape varieties by planted area. The main criterion for selecting the location of the research, apart from the assortment in the vineyard, was that the locations are situated as close as possible to the meteorological station from which the data for determining agroclimatic indices were processed.
Due to incomplete meteorological data, it was necessary to make a time interpolation for the missing meteorological data. Temporal interpolation of daily values of meteorological elements was applied (Perčec Tadić, 2010) in the adjusted vegetation period of the grapevine (April – October). If less than 35% of the daily data in a given year in the growing season were missing, the daily values were interpolated using measurements from a neighbouring station. If more than 35% of the data was missing during the year, no interpolation was done.
It is common for agro-climatic indices to be determined from 30-year series of meteorological daily data for certain meteorological elements such as air temperature, relative humidity, precipitation, solar radiation, etc. Looking through the sector of viticulture and winemaking, agroclimatic indices serve as a "tool" in determining geographical areas and their suitability for growing a particular grape variety or its rootstock, based on which maps of wine-growing areas are made. Thus, for example, the heliothermal index is used to divide different wine-growing areas in the world according to the temperature sums required for grapevine cultivation and grape ripening (Huglin, 1978). The Huglin index is a heliothermal index because it depends on the air temperature. It was introduced by Huglin (1978) and is used to divide different wine-growing areas in the world according to the temperature sums required for grapevine cultivation and grape ripening. The Huglin index is calculated according to the expression:

$$HI = \sum_{i=1.4.}^{30.9.} \left[\frac{(T_{mean} - 10) + (T_{max} - 10)}{2} \right] k$$

where T_{mean} is the mean daily air temperature, T_{max} is the maximum daily air temperature, and *k* is the "day length" coefficient. 10 °C is subtracted from the mean and maximum daily temperatures because the air temperature values are more than 10 °C of the active temperature for the vine. A temperature of 10 °C is also called the biological minimum temperature for the vine (Penzar & Penzar, 1985, 2000).
The archives of some wineries have several years of data on harvested product and qualitative parameters of grapes from different sub-regions of Croatia, whose analysis and comparison with the DHMZ climate data for the same period (2001–2018 and 2007–2018) found that the main climatic components affected grape production.
Uvometric characterisation of four studied cultivars was conducted in two consecutive years (2017 and 2018). The grape sampling of each cultivar was performed at full ripeness. Ten clusters were taken with five vines. Five clusters were taken from the sunny side and five from the shady side. The length and width of the photographed clusters were measured with the ImageJ program.

Results and discussion

According to the division of the Huglin index (HI) in the vegetation period from the beginning of April to the end of September in the wine-growing zones of Croatia in the periods 1961–1990 and 1989–2018, results indicate that northern and central geographical regions belong to the predominantly temperate, while other wine-growing areas belong to the moderately warm area for grapevine cultivation (Figure 1). In addition, comparing the obtained mean HI values between the two mentioned periods, they show its increase from approximately 200 to 300 ° C in the recent period. The impact of climate change on viticultural zoning and future potential in Croatia indicates further warming (Omazić et al., 2020). The differences between the two analyzed periods (2041–2070 and 1971–2000) showed that some indices in certain regions move into one to two of the following classes, which was especially noticeable in the eastern Pannonian basin and the mid-Adriatic coast. Most of Croatia is favorable for growing vines because the HI > 1500 °C, and unfavorable conditions for its cultivation are in mountainous Croatia (Vučetić & Anić, 2021).

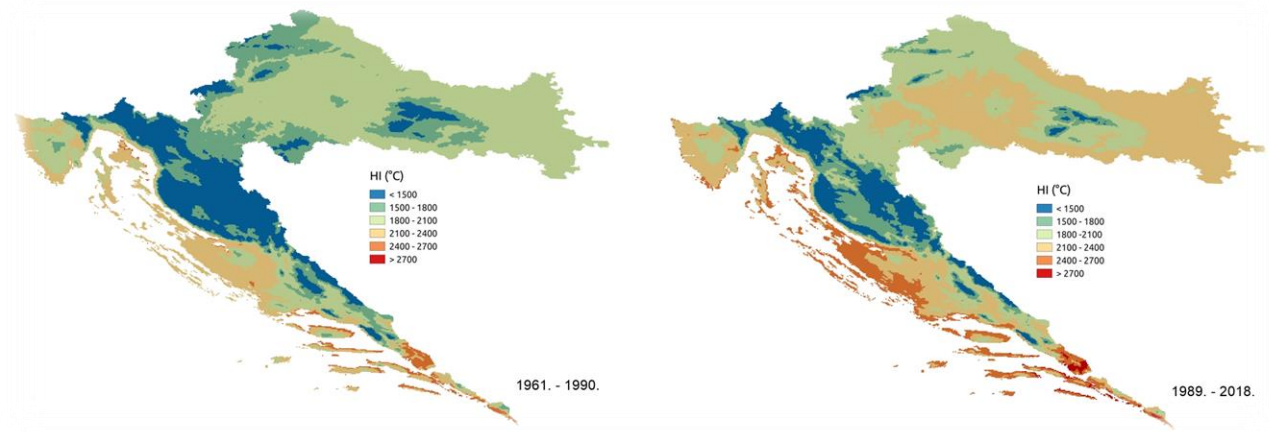

Figure 1. Mean values of the Huglin index (HI, °C) in Croatia in the vegetation period for the periods 1961–1990. (left) and 1989-2018 (right).

Table 1. shows the correlation coefficients (R) for the harvest date (day of the year), sugar content (°Oe) and total acidity (g/L) at the harvest of different varieties depending on the mean air temperature (°C) during the grape ripening period at different locations in Croatia in the periods 2001–2018 and 2007–2018. It can be seen that the mean air temperature significantly affects the earlier beginning of harvest of all four analysed varieties at all locations. The increase in the value of sugar content is significantly influenced by the mean air temperature on Graševina and Chardonnay at the Daruvar location in the Pannonian basin and Merlot at the Blato location at the mid-Adriatic Island. The decrease in the value of total acidity shows air temperature significantly affects Graševina and Chardonnay at Daruvar and Merlot at Korlat at the mid-Adriatic coast.

Table 1. Correlation coefficients (R) for the harvest date (day of the year), sugar content (°Oe) and total acid (g/L) in the harvest of different cultivars depending on the mean air temperature (°C) during the grape ripening period (verasion – harvest) at different locations in Croatia in the periods 2001–2018 and 2007–2018; ** for $p < 0.01$.

				Correlation coefficients (R)		
Variety	**Location**	**Meteo. station**	**Period**	**Harvest date (day of the year)**	**Sugar content (°Oe)**	**Total acidity (g/L)**
Graševina	Daruvar	Daruvar	2001–2018	-0.90 **	0.73 **	-0.63 **
Chardonnay	Daruvar	Daruvar	2001–2018	-0.89 **	0.51 **	-0.66 **
Plavac mali	Blato	Vela Luka	2001–2018	-0.65 **	0.29	0.66
Merlot	Blato	Vela Luka	2007–2018	-0.84 **	0.29 **	0.00
Merlot	Korlat	Zadar-airport	2007–2018	-0.72 **	0.36	-0.68 **

Based on 208 samples of clusters of selected cultivars Graševina, Chardonnay, Plavac mali and Merlot collected from 57 locations in Croatia, uvometric and statistical analysis of ANOVA determined the mean values of mass, width and length of clusters and the average weight of one berry and the average number of berries per cluster in 2017 and 2018. A comparison of the uvometric data of these two harvests (Table 2) showed that the average values of mass, width and length of the cluster, the mean mass of one berry and the number of berries per bunch in 2018 are significantly higher than in 2017. The average weight was 161.1 g in 2017 and 195.3 g in 2018. The length of the cluster averaged 16.4 cm in 2017 and 18.8 cm in 2018, and the width 11.6 cm in 2017 and 12.7 cm in 2018. The mean mass of one berry was 1.4 g in 2017 and 1.6 g in 2018. For the average number of berries per cluster, there is no statistically significant difference in the average number of berries in the observed harvests. The number of berries averaged 117.9 in 2017 and 121.1 in 2018. In the 2018 harvest, the mean values of mass, length and width of the cluster, the mass of one berry and the number of berries per cluster were higher than the values of the variables in the 2017 harvest. The reason for this can be related to the extremely hot and very dry summer of 2017 (in most of the mid-Adriatic even extremely dry) and the cold and rainy (in the mid-Adriatic even extremely rainy) September.

Table 2. Uvometry of grapes and berries by harvests in 2017 and 2018 and for cultivars Graševina, Chardonnay, Plavac mali and Merlot in Croatia.
*** and ** denote significance at the 1% and 5% levels determined by the F-test.

		N[1]	Cluster mass (g)			Cluster length (cm)			Cluster width (cm)			Mean mass of one berry (g)			Mean number of berries per cluster		
			Mean	STD	F	Mean	STD	F	Mean	STD	F	Mean	STD	F	Mean	STD	F
	In total	**208**	178.2	53.1		17.6	3.7		12.1	2.0		1.5	0.3		119.5	31.8	
HARVEST	**2017**	**104**	161.1 b	53.2	27.6***	16,4 b	3.7	85,9***	11.6 b	2.2	21.6	1.4 b	0.3	59.3***	117.9 a	36.0	0.6
	2018	**104**	195.3 a	47.4		18.8 a	3.3		12.7 a	1.7		1.6 a	0.3		121.1 b	27.2	
VARIETY	**Chardonnay**	**70**	168.7 b	43.7	8.1***	15.1 c	1.9	153,5***	11.4 b	1.8	23.5	1.5 b	0.2	32.3***	108.7 b	23.0	14.9***
	Merlot	**54**	196.5 a	67.2		22.4 a	2.7		13.3 a	1.9		1.4 c	0.3		140.8 a	38.5	
	Graševina	**52**	165.1 b	30.1		15.8 c	1.9		11.2 b	1.5		1.4 c	0.2		118.7 b	21.8	
	Plavac mali	**32**	189.2 a	64.3		17.9 b	2.4		13.2 a	1.7		1.8 a	0.4		108.6 b	33.2	

[1]*N – number of samples*

All F-test values indicate that the null hypothesis can be rejected at 5% test significance. Thus, it can be concluded that there is a statistically significant difference in the mean values of the observed variables with respect to the cultivar. The Graševina variety is grown mainly in the regions of continental Croatia, Plavac mali is grown mainly in the Dalmatia region, and Merlot and Chardonnay are grown in all wine-growing regions of Croatia. Significant influence of subregion on cluster mass, mean mass of one berry and mean number of berries per cluster was found (data not shown).

Conclusion

Significant changes were observed when comparing the recent climatological period (1989 to 2018) with a reference climatological period (1961-1990). Also, suitability of some new areas with higher elevation for commercial grapevine cultivation is expected in near future. It was confirmed that increased temperatures during maturation period have strong effects on earlier harvest dates for four important cultivars both in continental and mediterranean part of Croatia. This is usually accompanied with higher sugar content and lower total cidity of grapes. Significant regional and seasonal effect was confirmed also in case of grape uvometric parameters which can also be partially explained by the effect of different climatic conditions. All of the results presented indicated the presence of climate change in Croatia, which supports the hypothesis about the necessity to revise all wine growing zones in Croatia.

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