Doktorska disertacija – Sažetak
D.Sc. Thesis – Extended abstract

UTJECAJ EKSTREMNIH UVJETA U ATMOSFERI NA VINOVU LOZU U SADAŠNJIM I BUDUĆIM KLIMATSKIM UVJETIMA

The impact of extreme atmospheric conditions on vines in present and future climate

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Sažetak:

Brojna istraživanja ukazuju na promjene u temperaturi i oborini nad Sredozemljem kad promatramo prošle, ali i buduće klimatske uvjete pomoću klimatskih modela. Budući da te promjene značajno utječu i na biljni svijet, zapažaju se promjene u uzgoju vinove loze uzimajući u obzir kvalitetu uroda, ali i nastup fenofaza. Vinogradarstvo, u ekonomskom i tradicijskom smislu, predstavlja vrlo važnu poljoprivrednu granu u Hrvatskoj. Zbog toga je poželjno, ali i potrebno, proučiti učinak klimatskih promjena na uzgoj vinove loze u sadašnjim, ali i budućim klimatskim uvjetima.

Postoji više mogućnosti kako promatrati utjecaj klime na vinovu lozu, a najjednostavniji je pristup promatranjem različitih bioklimatskih indeksa. U tu svrhu promatrane su promjene pet bioklimatskih indeksa (srednje temperature u sezoni vegetacije, Winklerovog indeksa, Huglinovog indeksa, indeksa hladnih noći i indeksa suhoće) u razdoblju od 1961. do 2020. na meteorološkim postajama Državnog hidrometeorološkog zavoda. Rezultati ukazuju na vidljiv trend porasta temperature zraka, a posljedično i temperaturnih indeksa, posebno značajnog od kraja 1990-ih pa do danas. Osim toga, rezultati indeksa suhoće sugeriraju sve veći deficit dostupne vode u tlu, naročito na jugu Hrvatske. Ovi trendovi u temperaturi zraka utjecali su na trend sve ranijeg nastupa fenoloških faza (pupanja, cvatnje, šare i berbe) vinove loze. Budući da utjecaj meteoroloških parametara na fenološke faze nije jednostavno utvrditi i razlikuje se od sorte do sorte i od jedne do druge lokacije, razvijena su četiri statistička modela (dva temeljena na akumulaciji topline, dva na linearnoj regresiji) koja istražuju taj utjecaj. Osim toga, po prvi puta u Hrvatskoj testiran je biodinamički model STICS na četiri sorte vinove loze („Graševina", „Chardonnay", „Merlot" i „Plavac mali"). Rezultati testiranja ovih modela ukazuju na vrlo dobro slaganje modeliranih i opaženih datuma fenoloških faza za modele temeljene na akumulaciji topline, kao i za model STICS. Ova spoznaja omogućuje korištenje tih modela u kombinaciji s regionalnim klimatskim modelima kako bi se uvidjele promjene nastupa fenoloških faza i u budućoj klimi. Iz dobivenih rezultata vidljivo je da će se zbog porasta temperature datumi nastupa fenoloških faza u budućoj klimi pomaknuti još više prema početku godine. Ovo dovodi do dva moguća izazova u budućim klimatskim uvjetima: (i) pomicanje pupanja prema početku ožujka na kontinentu će dodatno povećati rizik od kasnog proljetnog mraza jer se datumi posljednjeg proljetnog mraza neće toliko pomaknuti i (ii) pomicanje šare prema kraju srpnja i početku kolovoza označava da će se krucijalni period vegetacije vinove loze, od šare do berbe, u potpunosti odvijati u najtoplijem dijelu godine, a samim time očekuju se daljnje promjene u kemijskom sastavu grožđa i posljedično vina.

Extended abstract:
1. Introduction

Many studies worldwide indicate that changes in temperature and precipitation significantly affect agriculture and food production (e.g. Fuhrer, 2003; Pandžić et al., 2022; Sviličić et al., 2016) and particularly affect the Mediterranean area (de Luis et al., 2014; Fernández-Montes and Rodrigo, 2012). As a result, food producers are increasingly faced with reduced harvests caused by numerous extreme meteorological conditions.

As an important agriculture sector in moderate latitudes, viticulture has been strongly influenced by changes in temperature and precipitation in recent years (Bock et al., 2013; Droulia and Charalampopoulos, 2022). There are numerous influences of different meteorological parameters on the cultivation of grapevines, composition of grapes, and the diseases that can affect vines. Bock et al., (2011) found that phenological stages were most influenced by average maximum temperatures of preceding months. Jones (2006) showed that the length of the growing season is directly related to the growing season mean temperature. The length of the growing season could also be linked to soil moisture, air temperature, and crop-management practices (Webb et al., 2012). Prolonged summer periods of extremely high temperatures can affect and slow down the physiological processes in the grapevine (Berry and Bjorkman, 2003).

The impact of climate change is greatly visible in the observed changes in the main phenological stages of grapevine: budburst, flowering, veraison, and harvest (e.g. Cortázar-Atauri et al., 2017; Urhausen et al., 2011). For example, many studies based on the measurements report earlier harvests (e.g. Koufos et al., 2014; Laget et al., 2008; Leeuwen and Darriet, 2016). Because temperature changes are more pronounced during the warm period of the year (Beniston et al., 2007), which is the vegetation period, a further shortening of the vegetation period is to be expected (Malheiro et al., 2010; Droulia and Charalampopoulos, 2021). This is also indicated by the numerous climate studies for different climate scenarios (e.g. Fraga et al., 2014; Ramos and Jones, 2018). However, although recent studies showed a positive correlation between temperature and earlier onset of most phenological stages under warmer climates (e.g., Fila et al., 2014; Fraga et al., 2017), the impact of climate change on budburst is not fully evident in different locations. It is important to emphasize that earlier onset of budburst indicates a potentially higher risk of frost.

Although the analysis of the impact of climate change on phenological stages can be estimated using climate models coupled with crop models, it is also possible to do a similar analysis with statistical phenological models (e.g., Fraga et al., 2016; Grillakis et al., 2022; Reis et al., 2020). A crop model simulates the vegetation cycle of different types of crops, either annual and/or perennial, herbaceous and/or woody in the soil-plant-atmosphere environment based on the balance of water, carbon, and nitrogen (e.g. Brisson et al., 2003). The numerical approach provides information far into the future in a biodynamically acceptable way, however, the crop modeling could have certain limitations due to many parametrizations used (e.g. Lalić et al., 2018). Various temperature-driven statistical phenological models have been used in numerous studies for determining the onset of phenological stages. The most frequently used models are based on growing degree-days (GDD), respectively calculating heat sum above a certain value which is necessary for a stage to start. Other ways to succeed in this is to use the crop model, such as the STICS (Simulateur mulTIdisciplinaire pour les Cultures Standard) model. STICS has been developed since 1996 at INRA and has been widely used for grapevine phenology prediction.

Also, numerous studies point to a further increase in temperature, which will lead to the continuation of the shift of phenological phases towards the beginning of the year. A special danger lies in delaying the budding towards the beginning of the year because it allows greater damage from frost.

Therefore, the overall objectives of the study were as follows; The first aim was to investigate the existence of shifts in the onset of the observed phenological stages of the four varieties (two white varieties, „Graševina" and „Chardonnay", and two red varieties, „Merlot" and „Plavac mali") which are, in terms of production, among the most represented and important in Croatia. The second aim was to develop a statistical approach to predict the main phenological stages (budburst, flowering, veraison, and harvest) using temperature and precipitation, as well as to parametrized STICS model for Croatia, so that these models could be used for coupling with climate models or for predicting future shifts of phenological stages. Then, to carry out analyses of bioclimatic indices for the first time in the future climate over Croatia filling the gap in the information on viticultural zoning in this part of Europe.

2. Data and methods

Daily values of minimum, maximum, and mean (Tmin, Tmax, Tmean; °C) air temperature, as well as daily precipitation amount (*P,* mm), from 80 meteorological stations all over Croatia from 1961 to 2020 were available for this research. The Croatian Meteorological and Hydrological Service (DHMZ) provided observations and data control. Established metrics for the quantitative evaluation of the viticulture in the context of climate suitability are bioclimatic indices: average growing season temperature (GST, Jones 2006), Growing degree-days (GDD, or Winkler index, Winkler et al., 1974), Huglin Heliothermal index (HI, Huglin, 1978), Cool night index (CI, Tonietto, 1999), and Dryness index (DI; Riou et al., 1994; Tonietto and Carbonneau, 2004). Since grapevines are heat-demanding crops (to complete their phenological stages) the first four indices are based on temperatures in the atmosphere, while the fifth one combines several meteorological variables.

The start dates of four phenological stages (budburst, flowering, veraison, and harvest) in 12 locations from 12 wineries throughout Croatia were collected. Four varieties (white varieties „Graševina" and „Chardonnay" and red varieties „Merlot" and „Plavac mali"), which make up most of the production in Croatia (~ 70%), were chosen for this study. Two of these varieties („Graševina" and „Plavac mali") are considered autochthonous and more than 50% of the wine produced is of these varieties. The other two varieties („Chardonnay" and „Merlot") are not native to Croatia but are well accepted and cultivated inland and in coastal areas. As the phenological data were rare but therefore very valuable, the available length of the sequences was tried to be fully used. Four statistical models were used to determine the beginning of a particular phenological stage. The first two models are based on determining the GDD thresholds required for phenological stage to start. The first model uses a base temperature of 10°C for calculating GDD, while the second one uses a base temperature of 5°C. Models numbered 3 to 4 use multiple linear regression to predict the onset of phenological stage occurrence using dependent variables: mean values of the minimum, maximum, and mean daily temperature (Model 3) and mean values of the minimum, maximum, mean daily temperature, and total precipitation amount (Model 4). Each of these four models also has two subtypes A and B. The A subtype of the model indicates that each variety is viewed as a unity and location is not taken into account. In this way, model calibration is done on a half of the stations listed as calibration stations. In this way, in addition to examining the influence of meteorological parameters on the cultivation of grapevines, it is also possible to examine whether the thresholds and parameters calculated at one location for a particular variety can also be applied at other locations for the same variety. For the analysis of the existing climate characteristics as well as for future climate projections, the results of Regional Climate Models (RCMs) from the EURO-CORDEX database (e.g., Jacob et al., 2014) at 0.11° grid spacing are used as well as output of ETHZ-CCLM-02 model at 0.02° grid. RCMs are forced by Global Climate Models (GCMs) with a moderate (RCP4.5) and a high-end (RCP8.5) greenhouse gas (GHG) scenarios. In order to determine future changes in bioclimatic indices spatial distribution of the indices in historical runs (1971–2000) is compared to two different 30-year periods (2041–2070 and 2070–2100). Also onset of phenological stages in this historical and future period is compered.

Also, 10 different methods for frost detection have been tested. Five of them have already been introduced in other studies but were not tested in the area of interest. The other five methods are proposed in this paper. The proposed methods are based on that the dew point temperature must be below 0°C for frost to occur. If the air is saturated, its temperature is called the dew point temperature because any further temperature drop causes condensation and dew formation (Lalić et al., 2018) and we could assume that if this temperature is below 0°C, ice cristal could be formed. The dew point temperature is calculated using the Clausius-Clapeyron equation, and the Tmin is measured each morning at 2-m height. Depending on the method, RH at 07 CET or RHmean were used to calculate Td since there are no measurements of relative humidity at the exact time when the air temperature reaches the minimum value. In this research, the minimum temperature threshold for methods 6–10 was not calculated separately, but the threshold was set in the range of 2°C and 3 °C every half degree, respectively. This assumption is in agreement with the results of the study Zaninović and Gajić-Čapka (1999) for Zagreb-Maksimir station for a 10-year period (1971–1980) in the cold part of the year (September–May). Their analysis showed that the minimum air temperatures at 5-cm height are lower 2–3°C than the minimum temperatures at 2-m height during clear/calm, clear/windy and partly cloudy/calm situations. For more transparent results, methods were evaluated in three seasons: the whole year (January–December), spring (March–May), and autumn (September–November).

3. Results and concluding remarks

All calulated temperature bioclimatic indeces (GDD, HI, GST and CI) show a decrease in values during the 1960s and 1970s and an increase from the 1980s onwards which is particularly pronounced since the early 1990s. During the 1960s and 1970s, there was a downward trend in temperature, visible on GDD and more pronounced in continental regions. The downward trend in temperature and agrometeorological indices in the last century was also noted in other works (e.g., Fioravanti et al., 2016; Ruml et al., 2022; Vršič et al., 2014). The year 1980 is typically referred to as a turning point where trends shift upward. The cooling trend was presumably due to a widespread decrease in surface solar radiation (global dimming of solar radiation) between the 1950s and 1980s (Wild, 2009), which affected the global temperature change (Broecker, 1975). Broecker (1975) concluded that a temperature drop during the middle of the last century was caused by the natural climate cycle, which overcame temporarily the warming effect of contemporary increased CO_2 content in the atmosphere. He predicted that the warming effect of the atmosphere would exceed the cooling effect caused by natural climate variability owing to the further exponential increase in CO_2 concentrations towards the end of the 20th century. Concerning the GDD values in the Dalmatia region (Fig. 2d), it should be noted that 1994 was the first time that a station recorded a GDD value above 2700°C units, which is classified as Too hot (Tab. 1). Over the next nine years, there was a situation where at least at one station, the GDD value exceeded that limit, and in 2018 at one station it exceeded 3000°C units.

Such changes in regions have been recorded in numerous studies across Europe in recent years. Koufos et al. (2018) showed that the GDD trend for the baseline period (1981–2010) in Grece was from 28 to 140°C units/10 years. In northeastern Spain (Ramos et al., 2008), a positive trend of GDD is visible, and research in Croatia shows that the growth of the indices will continue in the future.

If we look at the general appearances of all phenological stages, we can state that they mostly appear at earlier dates in the season. Although the trends themselves are rarely significant (the reason can also be a relatively small number of years), it is clear that they are the most significant for harvesting and budburst. The most dominant trend for budburst was recorded in Erdut_V4 for „Graševina" (-1.5 days/year which indicates -15 days/10 years), but the series has only 4 years of observations. In Kutjevo_V1 and Križevci_ V6, the trend is also negative and slightly less than -1 day/year. The only station where the trend is not noticed is Daruvar_V2. For „Chardonnay", these trends are similar or in some locations more marked. At the only maritime (coastal) station where data for „ Chardonnay" are available (Poreč_V7), the trend is most pronounced (-1.1 day/year). It should be emphasized that for „Chardonnay", budburst generally occurs a few days earlier than for other varieties. Similar results were obtained for red varieties. For „Merlot", one station (Poreč_V7) has a positive trend, and for the other station (Zadar_V9) trend is negative. For „Plavac Mali", the time series is the longest, and at both coastal stations in Dalmatia, Hvar and Lastovo, the trend is negative but more pronounced at Hvar, which is the only significant one (-0.39 days/year). The harvest of white cultivars showed mostly a negative trend, which means earlier harvests. In the case of white varieties, the trends are more pronounced for „Graševina" than for „Chardonnay". The trends for „Graševina" are mostly up to -1.4 days/year (or up to ~ -14 days/10 years). Positive trends are observed at the Poreč_V7 and Erdut_V4 stations. The reasons at the Erdut_V4 station could be due to the short period of observation, and in Poreč_V7 due to the virus diseases that occurred in the vineyard in recent years, which delayed the ripening process of grapes.

Four statistical phenological models, described in Table 2, were used to predict the onset of phenological stages. Their analysis is shown in Table S2.6 and Figures 5 and 6 for each cultivar and main phenological stage. Overall, the GDD approach provides better results than multiple linear regression. STICS model also gave good results for white varieties, but for red varieties (expecialy „Plavac mali") results were not so satisfactory. Overall, results showed possibility of using statistical models for future prediction of phenological stages.

The results show that a shift in phenological phases is expected in the future, regardless of the cultivar. The robustness of future changes depends on the localization analyzed and cultivar. An earlier start of budburst up to 20 days is expected by the end of the century. Moving budburst this early could increase the risk of frost in continental Croatia. Even more significant shifts are in the onset of harvest (especially if statistical models are observed). Postponing the harvest also means a reduction in the growing season, and a further reduction in the period from veraison to harvest is also visible. This could lead to an increase in temperature-dependent sugars, and that period would then come in an even warmer period.

An increased risk of frost is also expected in the future climate. The results of testing methods for frost detection indicate that the method that uses T_{min} of 3°C and $T_d < 0°C$ for detection gives the best results. Using RCMs and this method, the expected reduction in the number of days with frost is obtained both on an annual level and in spring. However, the shift of the last spring day with frost towards the beginning is less than the shift of the budding date. It is expected that the last day with frost in continental Croatia will move 10 days towards the beginning of the year. Budding shifts are greater and this indicates possible challenges for winegrowers in the future.