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Climatic Features Of Spring And Autumnal Frost Occurences In The Wine Regions Of Hungary (1961-2010)

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Abstract.

While frost is a natural phenomenon in Hungary from autumn to spring, frost damage, causing crop damage and yield reduction or even harvest shortfall, does not occur every year. The aim of the study was to estimate the occurrence and frequency of frost damage in fall, winter and spring using the CarpatClim data base, in the wine regions of Hungary. The daily distribution of the LT_{50} function between September 7 and May 15, using the Cold Hardiness model which contains 23 grape varieties, the occurrence probability of fall, winter and spring frost damage was determined. The extent of frost damage, frost duration and strength of frost is significantly affected by tolerance of grape varieties. We analysed the extent of fall, and spring frost damage respectively for frost susceptible, moderately frost-tolerant and frost-tolerant grape varieties. We examined the step overs of frost damage thresholds using CARPATCLIM database during the period between 1961-2010. The results not only provide frost damage quantification, but they may also help to judge the complex value of cultivation areas more accurately and to parameterize the crop safety of wine regions.

Keywords: frost damage, LT50 function, wine regions, wine grapes, CarpatClim data

1. Introduction

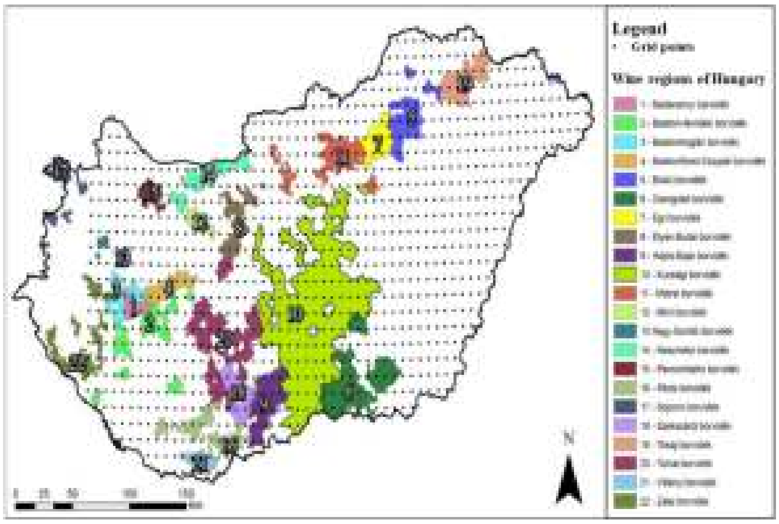
Frost is one of the most extraordinary phenomena in nature. However, from a meteorological point of view, frost is not an extreme phenomenon, as it is only a segment of the temperature range of our environment. Nevertheless, it can induce physiologically significant, irreversible changes in living cells. Cell injury or dehydration are the main cause of severe frost damage in most plants. The frost range is quite wide on Earth, with the lowest ever recorded temperature of nearly minus 90 degrees (-89.2 °C), recorded on July 21, 1983 at the Vostok Research Station in the South Pole. The lowest temperature so far in Hungary, which was measured on 16 February 1940 in Miskolctapolca, may seem insignificant compared to this being -35.0 °C.

It is very important for domestic viticulture to find out the changes in the extent and nature of frost occurrence in the main wine regions over time. The occurrence of frost from autumn to spring is a natural feature of our country. If its value falls below a threshold dependent on the particular grape variety, frost damage occurs. The increasing risk of frost in spring, or the increasing warm periods during winter can cause severe difficulties, or even significant yield losses. By studying changes over time, we can answer whether the trends of the examined variables support these fears. Previous frost studies (Oláh, 1979) were mainly aimed at determining the frequency of days with different threshold temperatures (Dunkel & Kozma, 1981): that is, temperatures of minus 17 °C and minus 21 °C. Frequencies were analyzed for domestic wine regions. Recently, more and more studies have been published on how index values , calculated for different climate scenarios such as the Huglin index (Huglin, 1978), have changed in recent decades and how they will change in the future (Horváth, 2008; Mesterházy, 2013). In this study, climate scenarios were not only examined for the previous threshold minima, but also introduced new minimum index categories, such as the number of frosty days below -15 °C and below -18 °C (Szenteleki et al. 2011). As our climate warms, fewer days below -21 °C will occur. The changes in 10-year increments may not be noticeable, therefore, we will not be able to quantify the changes. The occurrence of frost damage has already been studied in domestic apricot and peach plantations (Szalay et al. 2000; Lakatos et al. 2005). Knowing the LT50 values, the number of days that cause significant frost damage in the pre-rest, rest, and forced-rest periods and the probability of their occurrence can be accurately determined. The results can be used to quantify the extent of frost damage. Using these data, the complex value of each production site can be more precisely assessed, i.e., the yield safety of the areas can be parameterized (Lakatos et al. 2006).

2. Materials and Methods

The CARPATCLIM database was used for the temporal and spatial analysis of frost damage. Daily minimum temperatures were analyzed for the period 1961-2010. The available climate database does not fully cover the country, so only 21 of the 22 domestic wine regions could be examined (Figure 1).

Figure 1: The Hungarian grid points of the CarpatClim database and the location and numbering of the studied wine regions.



Source: R. Nagy, S. Molják

The Sopron wine region is not included in the study and the coverage of the Zala wine region is not complete as the wine region continues beyond the available database. The 7 grid points that characterize the wine region cover approximately two thirds of the area, so we included the region but characterized it using the available data points. We have an average of 14 grid points for characterizing a wine region. However, this shows a rather wide variation by wine region, since the Kunság wine region was analyzed on the basis of 100 points, while the Nagy-Somló, Badacsony, Villányi, Móri wine regions were only be analyzed on the basis of 3 grid points.

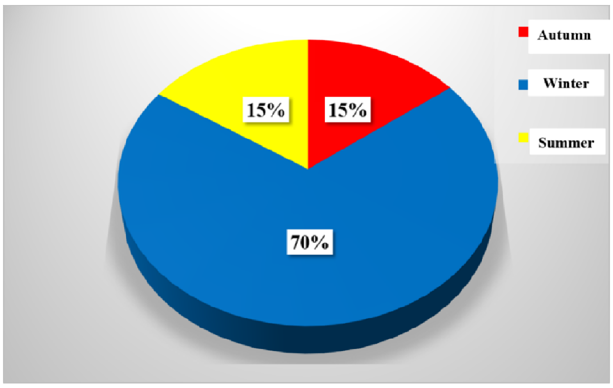
ArcMap 10.4 GIS software was used to display the results in space. Based on the database, we created a point grid (0.1˚ x 0.1˚) and then the results were applied to the points. Raster maps were generated from the value of the points by spline interpolation. The spline is an interpolation function that estimates the value of intermediate points by following the shape of a 'flexible membrane' based on fixed input points, minimizing the curvature of the entire surface. The result is a smooth surface that contains the values of all input points, but has a minimal curvature.

3. Results and Discussion

3.1. Frost occurrence in domestic wine regions

While frost is a natural phenomenon in our country from autumn to spring, frost damage, which causes plant damage and crop loss or even crop failure, does not occur every year. The occurrence of frost is an easily measurable or predictable meteorological phenomenon. To produce frost statistics, you can determine the number of days or hours below 0 °C, monthly, seasonally, or during the vegetation or dormancy period. In this study, we analyzed the incidence of autumn, winter, spring frosts in domestic wine regions using daily minimum temperatures. Autumn frosts are usually not a problem for grapes, as there are wines, such as "ice wine", which are typically made from grapes that have been frozen or have previously undergone a freeze. In this way, the grape's content values such as sugars, acidity will be more favorable, as they will have higher dry matter content and concentration. Of course, this process produces sweet and high acidity wines only in mild frosts. If the autumn frosts are severe and occur early during the beginning of dormant periods they can cause severe and irreversible damage to the buds. In winter, when the grapes are in the dormant stage, they tolerate relatively low temperatures relatively well. However, in the case of frost below -25 °C, most of the domestic wine regions suffer significant damage. During the dormancy period, the minimum temperature that grapes can withstand without frost damage changes daily. Spring frost damage poses a risk for cultivation if it occurs after the onset of budding and sap flowing. If the global temperature increase causes budding dates to be shifted, even frosts in late March may cause frost damage in the future. As a result of warming climate, the number of frosts will also decrease, and frosts in May or April will become less frequent. But a single frosty day is enough to cause frost damage. If the rate of withdrawal of spring frosts to the earlier period of the year exceeds the rate of the shift of vegetation period to the previous calendar period, a significant decrease in frost risk is expected in the future. If this condition is not met, the likelihood of late spring frost damage similar to or even greater than in previous years may occur in the coming decades. The figure below shows that autumn and spring frosts can be expected with the same frequency of 15–15% in the Hungarian wine regions (Figure 2).

Figure 2: Percentage distribution of frosts occurring in different seasons in Hungarian wine regions 1961-2010

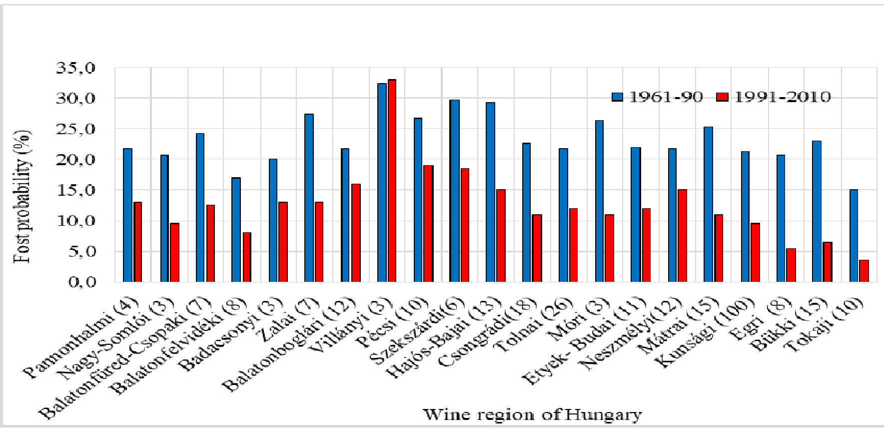


Previous winter and spring frost tests have statically investigated winter minimum temperatures. They assumed that when the minimum temperature drops below a certain threshold, frost damage may occur. This is indeed the case if a sufficiently low threshold is chosen. However, it is not necessary to have very low temperatures for frost damage to occur to the examined plant if the frost occurs before or after the dormant period. Most of the studied grape varieties show very good frost tolerance during the dormant period, but before or after the grape reaches this state, the degree of frost tolerance changes significantly. Previous studies did not take into account that the dormancy period of vines and other fruit trees, and consequently their frost tolerance, is a dynamically changing process.

3.2. Minimum temperatures below -1 °C during the growing season

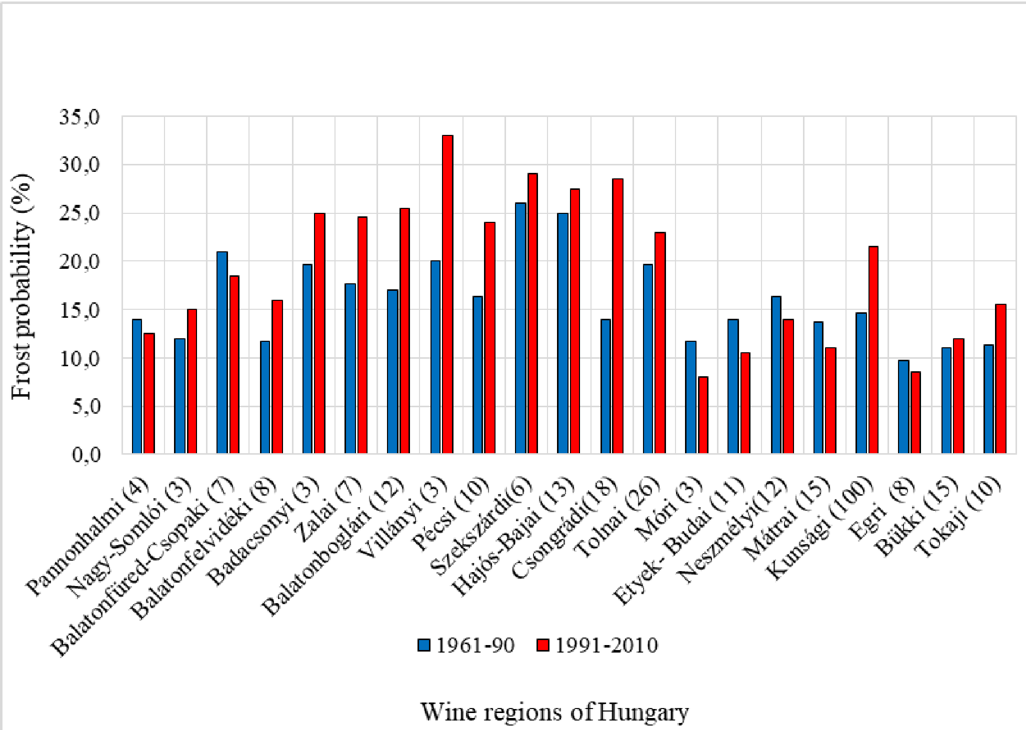
The vegetation period for grapes can be calculated from the average daily temperature exceeding 10 °C for at least 7 days. Of course, during the vegetation period, the average daily temperature can fall below 10 °C for several days. In this case there is no plant growth, no weight gain, but plant processes do not stop until the average daily temperature drops below 10 °C for 7 days. When that happens, the plant enters a period of rest. Days below -1.0 °C degree in spring, especially during the late spring, April and May, pose a risk to the grape growers. In the summer, between June and August, we do not have to deal with this phenomenon. However, low temperatures can occur in summer, which can also cause stress to the grapes. Generally speaking, temperatures below 5 °C can be considered as a significant cold effect at this time of year, which can reduce the value of the quality indicators of the berries, such as sugar content. At the beginning of the vegetation period, in the spring period, we have to expect frost about every 5 years. The most risky conditions for cultivation in the examined wine regions are the Villány wine region, where the probability of spring frost is 32.6%, i.e., we can expect spring frost every three years. The lowest spring frost risk (10.4%) is expected in the Tokaj wine region. In this wine region we have to deal with spring frosts every 10 years. The beginning of the vegetation period is shifted almost 10 days later in this region, so during the period from the end of April to the end of May frost damage is less likely to occur. If we compare the values of the frost probabilities from 1961–1990 and 1991–2010 in Hungarian wine regions, we can conclude that the spring frost risk has significantly decreased in recent decades. On average, the probability of frost occurrence in the Hungarian wine regions changed from 23.3% to 12.7% (Figure 3). In the Bükk wine region, the decrease in the occurrence of spring frost was the greatest, with its value reaching 16.5%. In the Villány wine region the probability of spring frost has not decreased, but increased by nearly 1% in the last 20 years compared to the previous 30 years.

Figure 3: Changes in frost probabilities below -1 °C during the spring vegetation period in Hungarian wine regions between 1961-2010.



Early autumn frost does not usually pose a significant problem for the vineyard. There may be quality problems with the sale of fresh grapes after frost. In the case of wine-grape cultivation, we can expect a decrease in quantity with berries that are prone to it. A slight frost can increase the sugar and acid content concentration which can be measured after the frost. However, more intense autumn frosts can damage buds on unripe canes, affecting next year's crop. The autumn frost shows a very strong regional variation in Hungary. During the autumn part of the vegetation period, frost can be expected on average every fifth or sixth year. During the period 1961–2010, the domestic wine regions were characterized by an average frost probability of 17.3%. Autumn frost was the least likely in the Eger wine region (9.2%), while in the Szekszárd wine region the occurrence of autumn frost was more than 27%. If we analyze the temporal variation in the likelihood of frost, we can see that autumn frosts have become more prevalent in many wine regions over the past two decades than in previous decades. In the period 1991–2010, autumn frost was on average 3% more likely to occur during the vegetation period than in 1961–1990. As shown in Figure 4, the autumn frost risk in the Csongrád wine region increased by 14.5% and in the Villány wine region by 13% compared to the base period of 1961-1990.

Figure 4: Changes in the probability of frost below -1 °C in Hungarian wine regions during the autumn vegetation period in Hungarian wine regions between 1961–2010.



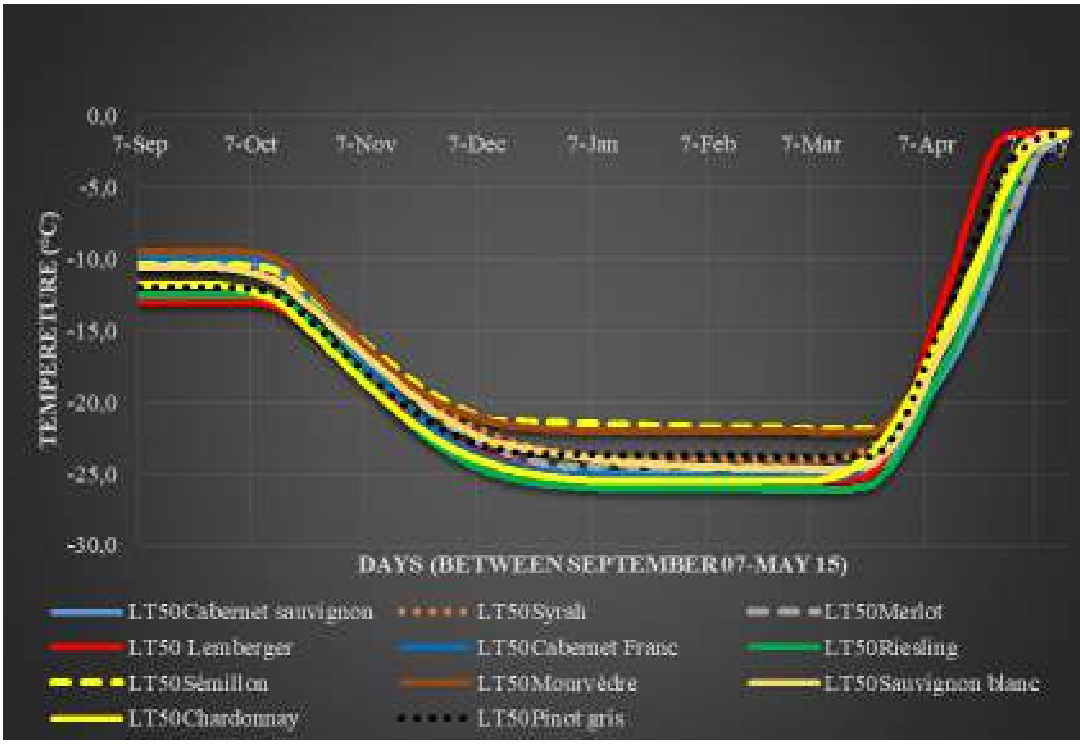
The increase in frost risk in the fall may even create favourable conditions for the production of special wine varieties, such as “ice wine”, and may also assist in the production of other wine specialties. However, it may pose a risk for late harvesting of freshly consumed table grapes. More frequent early-autumn frosts can cause bud damage in some wine regions, where local microclimatic conditions may cause frosts to appear more intensively and last longer.

3.3. Derivation of LT50 values

Defining frost damage is a somewhat complex task. The extent of injury to individual plant parts, shoots or flower buds caused by frost, i.e. the extent of frost damage, can be determined from plant samples placed in freezing chambers. If the test plant, or parts thereof, are cooled to a certain temperature, some samples will die completely, while others will not suffer any damage after warming. By knowing the lethal minimum (LT) temperatures, it is possible to determine how long parts of the plant can be cooled without permanent damage. LT values differ significantly between plant species and varieties. There are excellent, good and less frost tolerant varieties. Frost susceptibility tests are designed to accurately determine the percentage of plant samples that are damaged when cooled to below freezing point (Mills et al. 2006). Generally, 3 lethal temperature categories, i.e., that is the frost damage categories, LT10, LT50, and LT90 are usually tested. LT10 means that if the temperature is lower than the lethal temperature, 10% of the samples tested suffer frost damage. In this study, LT50 was determined using a model developed by Washington State University (Ferguson et al. 2011). The lethal minimum temperature of at least 50% frost damage was determined from 50-year averages. The average LT50 function was determined separately for each wine region examined. The input parameters of the model were daily minimum, maximum, and average temperatures. In this study we have determined the lethal minimum function on the basis of daily averages of many years instead of annual determination. We did not take into account the effect of the year-on-year temperature changes, since our aim was not to compare the vintages but to assess the frost sensitivity and frost risk of the wine regions, and for this purpose the daily data of multiple years between September 7 and May 15 for each vine regions is suitable. The model determines the lethal minimum function course for 23 grape varieties for the entire dormancy period (Ferguson et al. 2014). For the sake of ease of handling, we reduced the number of varieties examined, i.e., we examined the frost tolerance of the “warmth preferring” international varieties grown in Hungary, and Mediterranean varieties. The study of Mediterranean varieties is justified by the fact that, due to global warming, we will be able to grow these varieties in the future in the Carpathian Basin. Varieties accustomed to warmer climates are likely to exhibit greater frost risk than our domestic varieties.

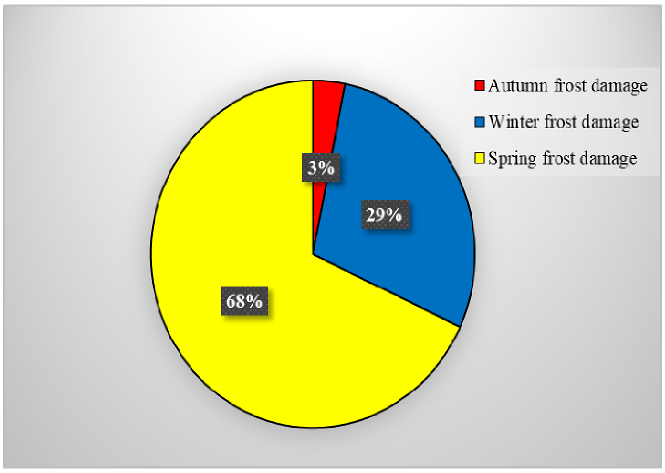
Based on the long-term daily average, minimum and maximum temperatures, the LT50 function was calculated for 21 wine regions and 11 grape varieties. The varieties include particularly frost tolerant varieties such as Riesling and Chardonnay, medium-frost-sensitive varieties such as Cabernet Sauvignon and Merlot, and frost-sensitive varieties such as Sémillon or Mourvèdre. However, the seasonal frost tolerance of the cultivars varies considerably. The one that has excellent frost tolerance in winter may show extreme frost sensitivity in spring. This is the case for the Lemberger grape, which has a very good frost tolerance in the winter, while in spring it was one of the most frost-sensitive varieties. Knowing the LT50 functions, we can determine the frost damage probability of the current domestic varieties or varieties recommended for Hungarian cultivation in the future, which could be adapted to the domestic climatic conditions. Using the available model, LT50 values were determined for each site and variety from September 7 to May 15, based on the long-term daily average, minimum, and maximum temperatures for each site. Thus, the derived function contains only temperature parameters, but does not take into account the autumn moisture values of the soil and its changes, nor the changes in the moisture content of the canes at the end of the vegetation period. There are significant differences in the course of LT50 functions between wine regions and varieties during the examined period. In the Eger region, it can be clearly seen that Kékfrankos has one of the best frost tolerances in autumn and winter, but in spring it is one of the most frost-sensitive grape varieties (Figure 5). Riesling has been shown to be one of the most frost tolerant varieties tested, but in the autumn period Lemberger outperforms its frost tolerance. Not surprisingly, the difference between the maximum winter frost tolerance of Mediterranean and domestic varieties can reach up to 5 °C. The difference between the varieties' frost tolerance is greatest in spring and late April. The difference between the LT50 function values calculated by the model can be up to 8 °C.

Figure 5: Evolution of temperature values (LT50) affecting at least half of the population in the Eger wine region for the examined grape varieties.



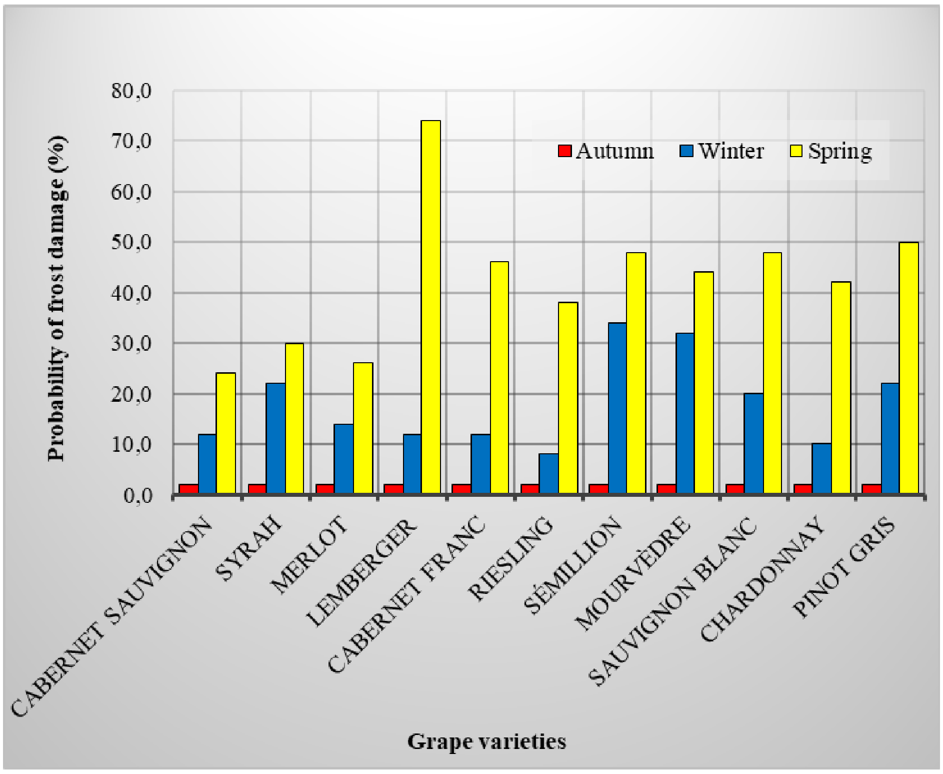
By producing lethal minimum functions for each of the 11 grape varieties studied, it is possible to determine the incidence of frost damage in autumn, winter and spring. In addition, we can calculate the probability of annual frost damage for the 21 wine regions. While the likelihood of frost occurring is the same in the autumn and spring vegetation periods, the rate of frost damage in spring is significantly higher than in autumn. For the wine region as a whole, spring frost damage accounts for the highest proportion, with over two-thirds (68%) of frost damage occurring during this period, followed by winter frost damage, with a prevalence rate of 29%. Only 3% of frost damage occurs in autumn (Figure 6).

Figure 6. Percentage of autumn-winter-spring frost damage in domestic wine regions between 1961-2010.



Analyzing the probability values of the frost damage of the varieties, it can be clearly seen that not only is the likelihood of frost damage is low in autumn but there is no significant difference between the frost tolerance of the varieties. Cabernet Sauvignon and Merlot are very slightly more frost-sensitive than the other grape varieties examined (Figure 7). In the winter season, the Mediterranean varieties (Sémillon, Mourvédre) have the highest probability of frost damage. In a spring we can expect an extremely high risk of frost damage in Kékfrankos. The probability of Kékfrankos frost damage in a domestic wine region is more than 70%. Compared to this, the risk of frost damage to the second most frost-sensitive domestic variety, Pinot Gris, is significantly lower, which is "only" 50% in the spring period.

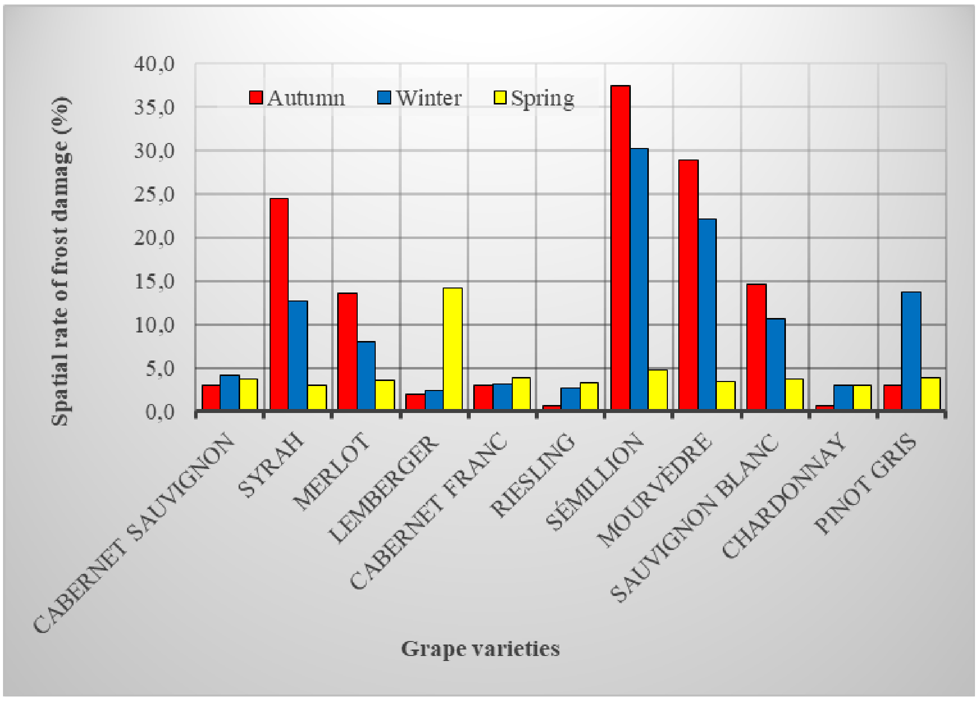
Figure 7: Distribution of at least 50% frost damage occurring in different seasons in the Hungarian wine regions for the examined grape varieties between 1961–2010.



Of course, the above results do not apply to the entire wine region. We also considered frost damage if only one data point in the wine region had the minimum temperature reached or lower than the LT50 function value for that day. If we analyze in detail the regional rate of frost damage in the Hungarian wine regions for the examined varieties, the following conclusions can be made:

Although spring frost damage is most likely to occur every year and autumn frost damage is the least common, in terms of area, autumn frost damage is about 2% higher than spring frost damage. Especially in the case of Mediterranean varieties (Sémillion, Mourvédre), frost damage occurs on a larger area than other varieties, but it does not exceed 40% (Figure 8). In winter, the same two Mediterranean varieties have the highest frost damage, but are 6–7% lower than in autumn. The regional rate of spring frost damage is generally below 5%. In spring, the frost damage of the Lemberger grape variety, which is otherwise very sensitive to frost, does not exceed 15% (Figure 8). In summary, frosts occur in a small proportion of Hungarian wine regions and, fortunately, it is rare for the whole wine region to be affected by frost damage. Because we are not sure which year and in which part of the wine region frost damage will occur, it is worth setting up long-term frost protection in all wine regions even with low territorial rate of frost damage.

Figure 8: The regional rate of frost damage occurring in different seasons in the Hungarian wine regions for the examined grape varieties between 1961–2010.



4. Conclusion

During the dormant period, predominantly extreme low temperatures can cause frost damage, while in the vegetation period even temperatures below -1 °C can cause severe frost damage. By monitoring the response of vineyards to the weather elements, we are able to take the necessary measures in time to ensure the undisturbed development of the vineyards and to protect it from harmful effects. If we know the statistical indicators of the occurrence of frost and the probability of the occurrence of frost damage, we will have the opportunity to recommend optimal varieties in the Hungarian wine regions.

Acknowledgment

The authors used the lattice point data of the following database in the points shown on the maps: CARPATCLIM Database © European Commission - JRC, 2013

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