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RESEARCHES ON THE FROST RESISTANCE OF GRAPEVINE WITH SPECIAL REGARD TO THE ROMANIAN VITICULTURE. A REVIEW

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Abstract

Under the temperate continental climate of Romania, very low temperatures during the winter (below -20ºC) can cause severe damage in several wine regions. The relatively high frequency of the low temperatures in winter allowed the classification of the autochthonous varieties of grapevine by their resistance/tolerance to frost. Thus, the varieties Aromat de Iaşi, Alidor, Ozana, Victoria, Transilvania, Băbească neagră, Cadarcă and Frâncuşă are frost sensitive, while Silvania, Crâmpoşie selecţionată, Şarba, Coarnă neagră, Fetească albă are resistant to winter frosts. The relatively high frequency of minimum temperatures harmful to grapevine during the dormant period, makes it necessary to assess the wintering behavior of vineyards. If during the reference period (1961-1990) the frequency of minimum temperatures below -20ºC in the Southern part of Romania (Bucharest) was 16.7%, in the period 1991-2018 it increased significantly to 39.3%. The higher frequency of minimum temperatures harmful to grapevine recorded in the main wine regions of the country (Hills of Moldova, Hills of Walachia and Oltenia, Transylvanian plateau) resulted in a significantly lower total wine production in the years 2005, 2010, 2012, 2015 and 2016. In a long-term experiment carried out on Fetească regală variety, a reduction of the average grape yield by 27-34% was found under the conditions of minimum temperatures of -20 ... -22ºC, in the dormant period. The paper reviews research on the physiological and biochemical aspects, frequency and intensity of winter frosts, the resistance/tolerance of the different varieties as well as factors that influence the resistance to frost of grapevine.

Key words*: grapevine varieties, winter frost resistance .*

INTRODUCTION

Among the abiotic factors with negative influences on the vine are also low temperatures, which, depending on the time of registration, by the minimum level they reach, cause less or greater damage, up to the total destruction of the plants.

Under the conditions of the continental temperate climate in Romania, especially the low (negative) temperatures recorded during the winter are conditioning the area of cultivation of certain varieties, grapevine training systems, as well as other viticulture practices (Oprean, 1975; Ţârdea and Dejeu, 1995; Olteanu, 2000; Dobrei et al., 2011; Hill, 2011; Ivanov et al., 2016).

In the traditional viticulture in Romania, up to mid -20th century, in many wine regions the protected culture of vines was practiced, by covering the plants with soil, especially in the plantations located on the valleys, on the plains and at the base of slopes (Martin, 1978; Oşlobeanu et al., 1980; 1991).

In the second half of the 20th century, as a result of several studies on the resistance to frost of the varieties and the delimitation of areas of unprotected culture, the vineyard plantations were modernized using the semi-high and high training systems (Laszlo et al., 1974; Metaxa and Kovacs, 1976; Macici et al., 1983; Mustea, 2004).

Under the influence of the low temperatures exceeding the resistance level of the different organs of the vines, a necrosis of the buds can occur, reduction of fertility and productivity, partial or total loss of the yield, necrosis of the free annual canes, cracking of the wood, installation on sap leakages of saprophytic fungi and bacteria that can penetrate into tissues, installation of crown gall, anthracnose, etc., becoming dangerous for the survival of the vine (Mănescu et al., 1990; Burzo et al., 2005;

Podosu et al., 2009; Călugăr et al., 2009; Blaich, 2010).
The present review presents a synthesis of the experimental results in a large number of winegrowing centers and years and on an important number of varieties, from which the main morpho-anatomical and physiological-biochemical aspects involved in the frost resistance of grapevine, winter behavior of varieties and factors of influence. All these aspects are useful for recovering the losses from the affected plantations and a better zoning of the varieties (Dobrei et al., 2017; Cragin et al., 2017).

MORPHO-ANATOMICAL AND PHYSIOLOGICAL-BIOCHEMICAL ASPECTS

In our country there have been numerous researches on the resistance to frost of the grapevines in correlation with the morpho-anatomical particularities of the plants during the dormancy period (Radu et al., 1968; Chirilei et al., 1970; Băditescu et al., 1978; Burzo, 2015; Dami et al., 2016; Kaya and Kose, 2018).
The freezing temperatures vary depending on how the shoots maturation process was carried out. The acclimation of the grapevine is a gradual process. It starts with the formation of the periderm and thus browning of the shoots, the entry of the winter buds into dormancy, the redistribution of the nutrients from the leaves into the permanent organs of the grapevine (trunk, canes, roots) and the fall of the leaves.
The beginning of maturation is marked by the change in the color of the bark, as a result of the occurrence of the subero-felodermal zone and the formation of the suber. The depth of formation of the suber determines the degree of frost resistance. In the varieties with better resistance, the suber appears at a greater depth and with a greater number of layers.
Prolonged growth of shoots, excess rainfall in autumn causes insufficient maturation of the canes and therefore, a frost-sensitization of the grapevines (Dejeu, 2010).
The acclimatization of the vines to the action of freezing temperatures is achieved by accumulating reserve substances and by increasing the concentration of the solution in the cells. The resistance to frost is genetically controlled and only manifests after the plant has undergone a period of acclimatization, during which the decrease of the free water content in the tissues and the increase of osmotic pressure take place. This protects the cells from intracellular ice formation (Burzo et al., 2005).
In the first phase of the acclimation process, which overlaps with the ripening of the canes, an intense accumulation of starch takes place in the annual and multi-annual wood, the accumulation of total and protein nitrogen, and the decrease of the non-protein nitrogen quantity.
In the second phase, enzymatic hydrolysis of the starch takes place, during the short days of the autumn, in simple soluble carbohydrates, which increase the osmotic force of the vacuolar content and the concentration of cytoplasmic juice, especially in the bark tissues. Rapid hydrolysis of starch and biosynthesis of glucose, fructose, sucrose, and raffinose occur in frost resistant varieties (Popa and Popa, 1976; Tacu and Beznea, 1994; Eibach and Töpfer, 2015; Keller, 2015).
The frost resistance of the tissues of the grapevines is also determined by the increase of the water retention force in the cells, which can be achieved by modifying the predominant water form and especially by decreasing the amount of free water and increasing the bound water. The content in free and bound water is closely linked to the intensity of dehydration of the canes in various moments during the autumn-spring interval.
In the process of preparing the plant for wintering, reactions of enzymatic hydrolysis of the proteins and transformation into free amino acids, which are the most resistant forms to frost of the nitrogenous organic compounds take place. During the winter, a reduction in the intensity of respiration and transpiration of the annual canes and buds was ascertained, with a minimum in January-February; the decrease was more pronounced in the varieties with better resistance to frost.

FREQUENCY AND INTENSITY OF WINTER FROSTS

The frequency of low winter temperatures affecting the aerial part of the grapevine is relatively high. Between 1888 and 1985, the critical frosty winters for the unprotected grapevine were at intervals of 2-20 years, returning once on average every 10 years (Popa et al., 1966; Georgescu et al., 1986). The very cold winters were in the years: 1888, 1893, 1907, 1909, 1929, 1942, 1954, 1963, 1969, 1980, 1985. A particularly difficult winter for grapevines was that of 1929, when on sandy soils the root system (more sensitive than other organs) froze and entire plantations of grapevines grown on their own roots were lost (Teodorescu, 1929).

In the last three decades, as a result of climate change, it has been observed that, besides global warming, a higher frequency and intensity of absolute low temperatures were damaging to the grapevine (Bucur and Babeş, 2016; Bucur and Dejeu, 2016a; Bucur et al., 2019). Bucur and Babeş (2016) kept track of the frequency of low temperatures in the period 1991-2016, compared to the reference period 1961-1990 (Table 1).

Table 1. Minimum temperatures below -20°C recorded in Bucharest-Baneasa in the period 1991-2015 compared to the reference period 1961-1990 (Bucur and Babeş, 2016)

1961-1990	1991-2015
1963: -23.7°C (18.01.1963)	1997: -20.0°C (18.12.1997)
1969: -21.7°C (05.02.1969)	1998: -20.3°C (25.12.1998)
1980: -24.5°C (15.01.1980)	2002: -25.7°C (26.12.2002)
1985: -24.6°C (14.02.1985)	2003: -20.0°C (14.02.2003)
1987: -21.7 °C (31.01.1987)	2004: -20.8°C (13.02.2004)
	2005: -23.7°C (08.02.2005)
	2010: -24.6°C (26.01.2010)
	2012: -24.3°C (29.01.2012)
	2015: -20.8°C (08.01.2015)

Between 1961 and 1990, the minimum temperatures were recorded at intervals of 2-11 years, returning on average every 2 years out of 10. As a result of the climatic changes of the last three decades (1991-2015), the frequency of the low temperatures harmful to the grapevine (under -20ºC) has increased significantly, and low temperatures were registered at intervals of 1-5 years, returning on average every 4 years out of 10.

Absolute minimum temperatures are recorded mostly in January. Another negative influence on the grapevines are low temperatures (-10 to -16ºC) which occur during November and lead to losses of up to 50-70% of the bud viability, depending on the variety, the degree of hardening, the depth of dormancy (Oprea and Oprea, 1976).

Following the evolution of the absolute minimum temperatures in time for Bucharest-Băneasa and Iaşi (Bucur and Babeş, 2016), a decrease of temperature can be observed (Figure 1).

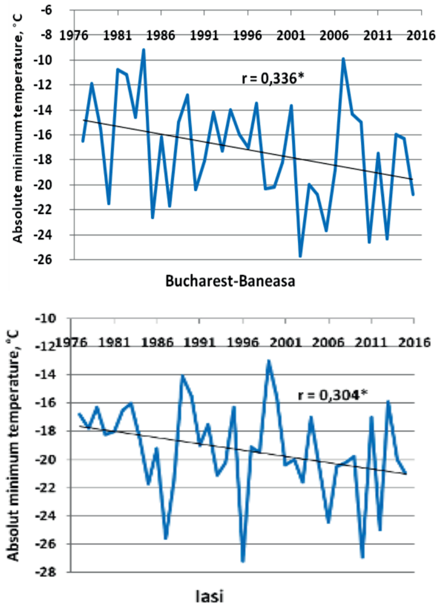

Figure 1. Evolution of absolute minimum temperatures between 1977 and 2015, Bucharest and Iaşi

In the southwest of the country, within the Banu Mărăcine winegrowing center, Cichi (2005); Cichi et al. (2006a and 2006b) a frequency greater than 26% of the absolute minimum temperatures was ascertained, with values between -18.1ºC and -22ºC, with a frequency of over 14% of minimum temperatures falling below -22ºC.

In the Târnave vineyard (Blaj) the largest winegrowing area in Transylvania, the low temperatures harmful to grapevines, between 2000 and 2018 (19 years) were recorded in the years: 2004 (-22.6ºC), 2005 (-22.1°C), 2006 (-20.2°C), 2010 (-21.4°C), 2012 (-21.6°C), 2014 (-21.7°C), 2015 (-23.3°C), 2017 (-24.1°C). In this wine-growing area, one of the coldest in Romania, the frequency of minimum temperatures below -20ºC for the studied period was 42.1% (Iliescu et al., 2019).

Extreme climatic phenomena have been frequently recorded in recent years and in the northeastern part of the country (frosts, prolonged drought, etc.) having more or less unfavorable impact on production and quality (Rotaru, 2008; Rotaru et al., 2008, 2010a, 2010b; Rotaru and Colibaba, 2011; Zaldea et al., 2013).

Numerous researches have considered the behavior of the grapevine varieties in the winegrowing centers Iasi and Cotnari, regarding the influence of the low harmful temperatures under the conditions of the winters 2010/2011 and 2011/2012 (Jităreanu et al., 2011; Irimia et al., 2012; Rotaru et al., 2013; Zaldea et al., 2014; Planchon et al., 2015).

During a long-term study (Bucharest, 1998-2018) on the Fetească regală variety, grafted on the Kober 5BB rootstock (Bucur et al., 2019), as a result of the high frequency of minimum temperatures below -20ºC large variations in production were ascertained, with a significant tendency of its decrease (Figure 2).

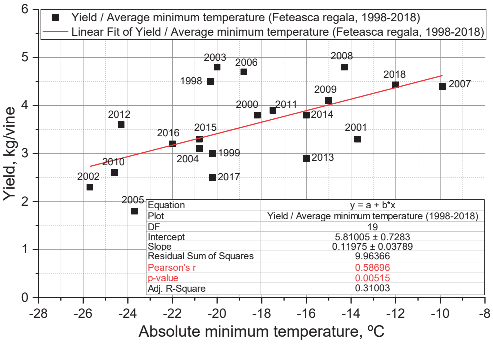

Figure 2. The negative effect of winter temperatures on grape yield (Fetească regală, Bucharest 1998-2018)

At minimum temperatures below -22ºC, a significant reduction in the average grape production (kg/vine) was recorded, compared to the normal winter years (from 4.75 kg/ grapevine to 3.2 kg/grapevine), representing a reduction by 33%. For the entire country, the minimum harmful temperatures recorded in many winegrowing regions of the country (mainly in Moldova, Walachia, Transylvania and Banat) lead to decreases in the total wine production (Figure 3) in 2005, 2010, 2012, 2015, 2016 by up to 50% (2005).

An important indicator of the conditions of grapevine wintering is the average of the minimum temperatures of the coldest month of the year (January). Following the average of the minimum temperatures in January in different regions of the country over a period of 38 years, Bucur and Dejeu (2016a) found large differences, from -3.57°C (Constanţa) to -6.0°C (Iaşi) and -6.26°C Cluj-Napoca; the last two regions have the most frequent temperatures harmful to grapevines.

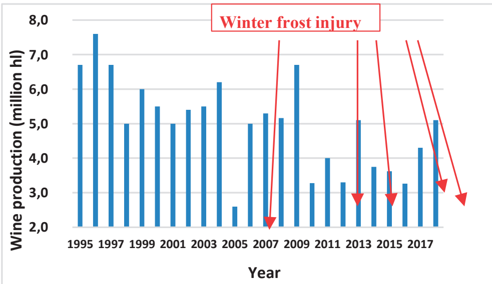

Figure 3. The evolution of the Romanian wine production and the influence of winter frosts between 1995-2018

BEHAVIOR OF VINE VARIETIES UNDER WINTERING CONDITIONS

The research carried out by Popa et al., 1966, in 7 wine centers, with reference to the influence of the low temperatures between -20ºC (Pietroasele) and -34ºC (Blaj) from winter 1962-1963, has shown that the varieties with best resistance to frost are: Coarnă neagră, Cabernet Sauvignon, Pinot noir, Riesling italian, Riesling de Rhin, Fetească albă, Aligoté and Perla de Csaba.

In the winter of 1984-1985, minimum temperatures critical for grapevine occurred in most of the winegrowing regions of the country. In Bucharest, -22.6ºC was registered on January 13, with a 44 cm snow layer, contributing to the protection of the base of the trunk, and intensifying the negative effect on the cordons, located near this layer (Georgescu et al., 1986).

The newly created varieties for table grapes (Timpuriu de Cluj, Cetăţuia, Victoria, Silvania, Roz românesc, Coarnă neagră selecţionată, Greaca, Xenia, Tamina), compared to the variety of Chasselas had a very low resistance to frost. Very low frost resistance varieties were considered Cetăţuia, Victoria şi Xenia. Newly created wine grape varieties (Aromat de Iaşi, Ozana, Codană) proved to be sensitive to low temperatures, except for Roz de Miniş variety.

A higher resistance, shown in the percentage of main and secondary viable buds, had Rkatiteli and resistant varieties Villard noir and Seyval. It is appreciated that a territorial distribution of varieties is required, according to their resistance to frost and the application of differentiated pruning based on the influence on the bud viability.

After the low winter temperature recorded in Bucharest-Baneasa weather station (-23.7ºC in February 9, 2005), Dejeu et al. (2005) have tested the frost resistance of 45 *Vitis vinifera* varieties. All the varieties were affected on different levels and they were grouped into four classes of resistance, according to the viability of the primary buds:

- high resistance to frost, with viability of the primary buds between 80 and 100% (Burgund mare, Columna, Furmint, Traminer roz, Riesling italian, Oporto, Muscat Ottonel, Cabernet Sauvignon);
- moderate resistance to frost, with viability of the primary buds between 50 and 80% (Rkaţiteli, Steinschiller, Şarba, Tamina, Muscat Hamburg, Frâncuşă, Pinot noir, Grasă de Cotnari, Augusta, Merlot, Fetească regală, Chardonnay, Fetească neagră, Aligoté, Coarnă neagră selecţionată, Sauvignon, Plăvaie, Timpuriu de Cluj, Creaţă, Chasselas doré);
- low resistance to frost, with viability of the primary buds between 30 and 50% (Novac, Azur, Fetească albă, Galbenă de Odobeşti, Kişmiş alb, Tămâioasă românească, Afuz Ali);
- very low resistance to frost, with viability of the primary buds between 0 and 30% (Crâmpoşie, Cardinal, Sangiovese, Victoria, Băbească neagră, Cadarcă, Timpuriu de Pietroasa, Italia, Muscat timpuriu de Bucureşti).

During the winter of 2009-2010, starting with January 24, three consecutive days with minimum temperatures below the limit of resistance of grapevine to frost were recorded, in most of the winegrowing areas of the country (Şerdinescu and Ion, 2010). In the vineyards in the northeast of the country, where temperatures up to -27ºC were recorded, the viability of the eyes of the representative varieties was between 0% (Feteasca albă) and 50% (Sauvignon). The largest losses of buds were recorded in the plots with northern, north-eastern exposure and at the base of the slopes, these being between 93% (Fetească regală) and 100% (Fetească albă).

In Odobeşti vineyard, after recording an absolute minimum temperature of -23.8ºC, the viability was between 33% (Şarba) and 81% (Fetească regală).

In Murfatlar vineyard (-20.0ºC absolute minimum temperature), the viability was lower for table grape varieties (Afuz Ali 93Mf - 3%, Perlette - 5%, Victoria - 10%, Muscat de Hamburg - 30%) and for wine grape varieties located at the base of the slope and in the lower third of it (Cabernet Sauvignon - 22%, Cristina - 30%, Mamaia - 35%, Fetească neagră - 40%). The viability was better for wine grape varieties located in the upper third of the slope (Columna - 62%, Pinot gris - 54%, Muscat Ottonel - 50%, Chardonnay - 50%).

In the Blaj winegrowing center (-21.4ºC absolute minimum temperature), the variety Fetească regală showed viability between 32% in the plantations located at the base of the slope, 43% in the plantations located in the first third of the slope and 83% in the plantations located in the highest third of the slope. In the variety Italian Riesling, the viability, under the same conditions, was between 42 and 91%.

Studying the behavior at low temperatures of -24.2ºC under the conditions in Bucharest (February 9, 2012), Stroe and Bucur (2012) found higher sensitivity in new table grape varieties to be in close correlation with that of the parents. Thus, the Azur variety (Coarnă neagră x Cardinal) had lower eye losses (56%) compared to Greaca (Bicane x Afuz Ali), where the losses were 96%.

Following the effect of the minimum temperatures of -20.8ºC (January 8, 2015) on a number of 45 new varieties (Bucur and Dejeu, 2016b), they found a better resistance to frost of the varieties Napoca (56% viability), Milcov (43%), Greaca and Xenia (42%), among table grape varieties. Of the varieties for wine studied, better behavior had Şarba and Crâmpoşie selecţionată (56%), Columna

(50%), Novac (50%) and Roz de Miniş (40%). The varieties Călina (6% viability), Transilvania (3%), Triumf (5%), Victoria (9%), Selena (3%) and Mamaia (5%) were the most sensitive to the action of low temperatures in winter.

Following the minimum temperatures of -22ºC (January 23, 2016), a better behavior in wintering had the varieties Silvania (48% viability), Câmpoşie selecţionată (72%), Şarba (59%), Haiduc (48%), Arcaş (43%), Negru de Drăgăşani (40%). The most sensitive ones were Azur, Călina, Muscat timpuriu de Bucureşti, Someşan, Selena, Blasius and Aromat de Iaşi (between 2 and 9%).

In the winter of 2016-2017, the minimum temperature harmful for the grapevine, of -20.2ºC was recorded again (January 10, 2017). Under these conditions, the viability of the buds was higher compared to previous years. The most resistant were the varieties Greaca (93%), Otilia (81%), Tamina (81%), Azur (78%), Timpuriu de Pietroasa (76%), Silvania (68%), Şarba (94%), Columna and Crâmpoşie selecţionata (79%), Pandur and Novac (93%), Negru de Drăgăşani (85%), Cristina (83%). The following varieties were the most sensitive: Muscat timpuriu de Bucureşti (21% viability), Transilvania (25%), Istriţa (28%), Milcov (30%), Băbească gri (12%), Selena (21%), Blasius (24%), Furmint de Miniş (25%), Codană (24%), Mamaia (28%).

Following a minimum temperature of -20°C recorded in the southwest of the country (Plenița - January 1, 2015) Cichi et al. (2016) classified the varieties studied in two categories:

- varieties with medium resistance to frost (25-50% killed buds): Fetească neagră, Cabernet Sauvignon and Riesling italian;
- varieties with low resistance to frost (50-75% killed buds): Syrah, Tămâioasă românească, Merlot and Sauvignon.

FACTORS DETERMINING THE FROST RESISTANCE OF PLANTS

There are a variety of factors determining the frost resistance of grapevines: the species, the variety, the organ of the vine, the duration and level of low temperatures, how low temperatures occur and pass, the alternation of low and high temperatures, variation of frost resistance in winter, topographic features, the level of previous year production, the rootstock, culture techniques, etc. (Gagea et al., 1991; Cotea et al., 2009; Haras and Rotaru, 2012; Costescu et al., 2012; 2013; Hajdu, 2013).

The *V. amurensis* species is very resilient; the American species used as rootstocks have a medium resistance and the varieties of the *V. vinifera* species are less resistant. Some of them (Cabernet Sauvignon, Coarnă neagră, Riesling de Rhin, etc.) have a slightly higher resistance than others (Cardinal, Perlette, Afuz Ali, Victoria, etc.). Martin, 1978, found that the freezing temperature of the winter buds is between -15 and -22ºC, the annual canes of the *Vitis vinifera* freeze at -22 ... -24ºC and the rootstocks at -28 ... -30ºC.

Buds losses due to low winter temperatures result in crop losses, variable based on temperature level and duration.

The longer the duration of the lower temperatures, the higher the degree of injury, not only the organs with lower resistance (winter eyes) are affected, but also those with better resistance (annual canes, multiannual canes of grapevine). For the same organ, the effects of low temperatures increase with their duration of action (Oşlobeanu et al., 1980; Olteanu, 2000; Cichi and Capruciu, 2018).

If at a temperature -18ºC no special losses are noticed, when the temperature drops to -22ºC, the production significantly starts decreasing, especially in the varieties with a lower resistance to frost. Thus, Fetească neagră variety showed a production loss of 45%, Cabernet Sauvignon 62%, Muscat Ottonel 86%, and Merlot, the less resistant, 91%. The decrease in temperature to -26ºC totally compromised the production. The yield losses, in the mentioned varieties, increased with the increase of the duration of low temperatures; compared to a duration of 3 hours, losses increased by 52% for a duration of 12 hours (Beznea D., 1986).

Generally, in the vineyards of Romania, a tolerance threshold at low temperatures up to -18 ... -20ºC for most varieties of table grapes and -20 ... -22ºC for wine varieties is considered (Oşlobeanu et al., 1980; Olteanu, 2000; Irimia, 2012).

If the low temperatures occur slowly, gradually, the grapevines can endure more easily the bud losses, which are lower than if the temperatures occur suddenly. With slow passage, there are lower injuries, even when they occur suddenly, compared to the sudden passage (Severin, 1972).

The alternation of low and high temperatures increases the effect of the low temperatures. The resistance to low temperatures is not the same throughout the winter. Under the conditions in Bucharest area, Oprea and Oprea (1976) found that in the first part of the vegetative dormancy (November, 27), the temperature of -16.2ºC affected 21% of the buds of the Fetească neagră variety and 58% of the buds of the Afuz Ali variety.

The highest resistance of grapevine to frost was found in January, in the middle of the vegetative dormancy (Severin, 1970; Milică and Severin, 1978). The topographic conditions influence the variations of the minimum temperature, which affect the behavior to frost differently. Irimia et al. (2012) found differences in the minimum temperature in Cotnari vineyard of up to -7.1ºC, depending on the location of the plots on different forms of relief.

Şerdinescu and Ion (2010) found important differences in the behavior under wintering conditions of the varieties depending on their location on the plot. Also, for the vineyards located in the north and northeast of the country (Iaşi), the plantations with northern and northeast exposure were the most affected by the frosts of winter 2009-2010.

The large grape yields obtained in 2004 with the variety Fetească regală, as a result of large bud loads to the pruning (20 buds/m^2), led to appreciable losses of buds in the winter 2004-2005, compared to the loads of 10 buds/m^2 (Dejeu et al., 2005).

The influence of the rootstock on the frost resistance of variety graft is indisputable. The varieties not grafted compared to the grafted ones, under the same environmental conditions, have a slightly higher sensitivity to low temperatures. The use of rootstocks with a longer vegetation period, of high vigor, leads to decreased resistance to frost, compared to rootstocks with a shorter vegetation period and normal vigor. Thus, the Cardinal variety grafted on the rootstock Riparia gloire, showed 75% lost buds, compared to 85.3% when grafted on Berlandieri x Riparia Kober 5 BB, after a frost of -19.5ºC (December 13, 1977). When grafting on Riparia gloire rootstock, the canes showed a content richer in starch, monosaccharides, bound water (Mănescu et al., 1990).

The high grapevine training systems and the attribution of moderate bud loads when pruning stimulate the growth vigor of the grapevines, improve the maturation of the annual canes and provide conditions for a better wintering of the grapevines (Burzo et al., 2005). Abundant fertilization and late irrigation delay the maturation process, cause accumulation of larger amounts of water in the cells and thus predispose the plants to frost.

Fertilization with nitrogen in moderate doses (100 kg/ha) on a background with phosphorus and potassium contributes to the increase of certain resistance properties of vines to low temperatures in winter (Popa and Motoi, 1980).

CONCLUSIONS

The frost resistance of grapevine is affected by genotype, organ, the duration and level of the low minimum temperatures, how low temperatures occur and pass, the variation of frost resistance during the winter, topographic conditions.

In the last decades, scientific research in the field of frost resistance of grapevines has significantly increased, due to the increased frequency and intensity of this abiotic factor, characteristic to climatic changes.

This knowledge can be used for a better zoning of the grapevine varieties, to establish measures that diminish the effects of this negative factor under sustainability conditions of the wine production.

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