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STUDY OF BLOSSOM FREEZING IN PEACHES BY MATHEMATICAL AND STATISTICAL METHODS

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Abstract

Fourteen varieties of peaches were included in the present study. The degree of blossom freezing (%) in two consecutive years 2019-2020 was studied. For this purpose, hierarchical cluster analysis and single-factor analysis of variance and Duncan's test were applied to assess the differences. It was found that the studied varieties can be grouped in four clusters according to similarity in the degree of frost in 2019 and in 2020. It was proved that in 2019 with the highest percentage of frost was 'El. 19-78' (98.33 %), followed by 'Ferlino', but with minor damage (50.67%). The varieties 'Evmolpia', 'Filina', 'Flavia', 'Redhaven' and 'El. 19-77' had no frozen blossoms. According to the degree of frost in 2020, the varieties formed three clusters, with 'Evmolpia' in a separate cluster, as a variety with minimal effects of low temperatures (59%). In 2020, the percentage of freezing of blossoms increased in most varieties: 'Ferlino' (92%), 'Puldin' (99%), 'Filina' (96%), 'Flavia' (92%), 'Maycrest' (98.67%), 'Redhaven' (99.67%), 'El. 7-59' (92%), 'El. 4-22' (94.67%), 'El. 91-23' (96.23%), and 'El. 19-78' (93%).

***Key words**: peaches, frost, clusters, dispersion analysis.*

INTRODUCTION

Peach is a heat-loving fruit plant (Petrov & Grigorov, 1981). The thermal regime affects the development of the peach tree during the different periods of vegetation and winter dormancy. During the winter dormancy, the peach tree satisfies its needs for cold. In order to pass the same period, the individual peach varieties require a different amount of cold with temperatures lower than 7°C. The peach tree is often exposed to extremely low temperatures. The flower buds are the most sensitive, followed by the core, wood, cambium and leaf buds.

In order for the peach tree to be stable at the same low temperature, it depends on several factors - hereditary varietal characteristics, degree of nutrient supply, degree of hardening, nature of the cold - gradually or sharply lowering the temperature, its duration of action. After satisfying the need for cold and the warming of weather, resistance begins to decline. It may rise again in the presence of constant negative temperatures. When the positive temperatures increase, the process of hardening is very fast, due to which, the cold resistance of the flower buds drops sharply. This happens most often in late February and March, when the development of flower buds begins.

As a result of a sharp cold snap on March 29, 2015, in the USA, Chen et al. (2016) proved that spring temperature drops have a critical impact on peach yields and led to serious complications in fruit growing. The effects of peach freezing and crop reduction as a direct consequence of this was analyzed. The presence of significant correlations between the tolerance to temperature anomalies and yields was proven.

Reig et al. (2013) examined frost-damaged blossoms in fifty-six varieties of peaches and nectarines obtained from different breeding programs over a period of two years. The tolerance of the varieties to low temperatures and the susceptibility of their pistils to damage as a result of frost were analyzed.

Miranda et al. (2013) claimed that the phenological evolution of peach can be adequately simulated by a simple sequential statistical model that involves cooling by a dynamic method, and forced heat accumulation, through increasing sums of degrees. They conducted a study and found that there is good accuracy for all varieties and stages of the test, and the studied parameters of the model make physiological sense. The results suggested that this method can be used to accurately assess the phenological evolution of these species in a wide range of climatic situations. This made it suitable for assessing the impact of climate change on crop phenology and for assessing the risk associated with climate and extremely low spring temperatures.

Szalay et al. (2009) study on the frost resistance of flower buds found that different parts of trees have very different levels of frost resistance and this resistance also varies considerably over time. During dormancy, flower buds were most sensitive to frost. The authors conducted a study in three consecutive winters with very diverse weather conditions. The freezing processes of overwintering organs were determined by environmental factors and mainly by temperature. Thus, in the same place, the degree of development of flower buds and the development of frost resistance might differ from year to year.

It is important to know the cold tolerance of peach varieties during the various phenological stages of flowering. Szalay et al. (2018) conducted an experiment for artificial freezing in a climate chamber in five selected years between 2007 and 2016. They determined the frost tolerance of the generative organs of three varieties of peaches at different phenological stages of flowering.

Their results showed that LT 50 values of the studied peach varieties in the phase of swollen buds on average for five years were between -6.8°C and -11.2°C depending on the variety, and with the progress of the phenological phases the cold resistance of the generative organs decreases. At the end of flowering, LT 50 values varied between -1.7°C and -4.1°C. This study showed that trees with delayed development were more susceptible to damage of flower organs by cold.

Szalay et al (1999) conducted a study on the artificial frost tolerance of peach varieties and found that during dormancy flower buds are the most sensitive organs of trees to frost. Their aim was to determine the frost tolerance of six varieties of peaches during dormancy. The buds were examined in artificial freezing tests and LT50 values were determined for each variety as well a sampling date. The authors determine that the frost tolerance of flower buds is highest in mid-December, regardless of the variety. The dynamics of the varieties were similar to each other.

In 1998, due to the mild weather in January, the frost tolerance of flower buds decreased rapidly and the LT50 reached -15°C by mid-February. In 1999, the decrease in the level of frost tolerance of flower buds was significantly lower due to the cold weather. LT50 values reached -15°C only in the first half of March.

Mokreva et al. (2001) studied the resistance of plants to environmental conditions by analysis of variance.

The aim of the present study was to examine the impact of low ambient temperatures on peach orchards.

MATERIALS AND METHODS

The experiment was conducted in the experimental base of the Institute of Fruit Growing - Plovdiv. The plants were planted in 2014 and refined on a peach seedbed. The trees were formed by the free-growing crown system planted at a distance of 5 m between rows and 3m in a row. They were grown under the system of black fallow and conventional plant protection. The subject of the study were eight varieties of dessert peaches ‘Ferlino’, ‘Laskava’, ‘Evmolpia’, ‘Puldin’, ‘Filina’, ‘Flavia’, ‘Maycrest’, ‘Redhaven’ and six selected hybrids, observing their phenological development. Experimental data on the degree of freezing of blossoms (%) of each variety in the period 2019-2020 were reported. Values were obtained on the basis of 300 examined blossoms, divided into three replications (one hundred plants), taken randomly from all parts of the tree crowns. ‘Flavia’ was created at the Institute of Fruit Growing - Plovdiv, Bulgaria. Its fruits ripened very early, June 15-20 and had an average weight of 140-150 g. They have good taste.

‘Maycrest’ was created in the United States. The fruits ripened on June 20-25. They were medium to large 150-160 g, and had a very good sensor profile.

‘Filina’ was established at the Institute of Fruit Growing - Plovdiv, Bulgaria. The fruits ripened 3-4 days after those of the ‘Maycrest’ standard.

They are very large with an average weight of 170 g. They have very good taste, surpassing ‘Maycrest’ in terms of fruit weight.
‘Redhaven’ was created in Michigan USA. The fruits ripened in late July - early August. They were large with an average weight of 160 g. The fruit flesh had very good taste. The variety was resistant to winter frosts and tolerates lower temperatures relatively well during flowering.
‘Puldin’ was established at the Institute of Fruit Growing - Plovdiv, Bulgaria. The fruits ripened in early August 2-3 days after the ‘Redhaven’ standard. They have excellent taste and an average weight of 180 g.
‘Laskava’ was established at the Institute of Fruit Growing - Plovdiv, Bulgaria. The fruits ripened on August 5-10. They were 250-300 g., red, with excellent taste. The variety had a high degree of resistance to *Sphaerotheca pannosa* var. *persicae* and good resistance to *Taphrina deformans.*
‘Laskino’ was established at the Institute of Fruit Growing - Plovdiv, Bulgaria. The fruits ripened in late August, they had an average weight of 210-240 g. It had high resistance to *Sphaerotheca pannosa* var. *persicae* and good resistance to *Taphrina deformans.*
‘Ferlino’ was introduced by Italy. The fruits ripened in late August. They were large with an average weight of 220-250 g. It had very good taste.
‘Evmolpia’ was created at the Institute of Fruit Growing - Plovdiv, Bulgaria. Its fruits ripened on September 10. They were very large 210-220 g. with a delicate texture, very juicy. The variety had a pronounced resistance to *Taphrina deformans.*
‘El. 7-59’ was established at the Institute of Fruit Growing - Plovdiv, Bulgaria. The fruits ripened after August 20. They had very good taste. They had an average weight of 240-260 g.
‘El. 4-22’ was established at the Institute of Fruit Growing - Plovdiv, Bulgaria. The fruits ripen in late August. The average fruit weight is 130-160 g.
‘El. 91-23’ was created at the Institute of Fruit Growing - Plovdiv, Bulgaria. The fruits ripened in late August. The average weight of the fruit was 180-210 g. It has a yellow-red color and bright yellow fruit flesh.
‘El. 19-77’ was established at the Institute of Fruit Growing - Plovdiv, Bulgaria. The fruits ripened on June 20-30 and had an average weight of 130-160 g. The skin was orange-red in color and the taste was very good.
‘El. 19-78’ was created at the Institute of Fruit Growing - Plovdiv, Bulgaria. The fruits ripened on June 20-30 and had an average weight of 120-150 g. The color was orange-red and the taste was very good.
Peach varieties were grouped through hierarchical cluster analysis by the method of intergroup binding and the quadratic Euclidean distance as a measure of similarity. A comparative assessment of the degree of freezing of the different varieties for each year of study was performed by single-factor analysis of variance and Duncan's test to assess the differences at a significance level of $\alpha \leq 0.05$. Graphic images visualizing the change of frozen plants during the two years of the study were constructed.
The reported negative temperatures in 2019 (Table 1) were from March. On March 4, the first negative temperature was reported -0.8°C for three hours and the lowest measured -1.9°C. The next measured temperature was also the lowest for the month -2.3°C and average -1.3°C with a duration of four hours. These first negative temperatures did not significantly affect the flower buds because their development had not begun yet.

Table 1. Minimum, average daily temperatures and duration of action for 2019 and 2020

Year	Data	Average negative temperature	Lowest negative temperature	Duration of the period (hours)
2019	4.3.2019	-0.8	-1.9	3
	5.3.2019	-1.3	-2.3	4
	25.3.2019	-0.2	-0.2	3
	29.3.2019	-0.8	-1.7	5
2020	16.3.2020	-1.2	-2.6	6
	17.3.2020	-2.3	-4.9	10
	18.3.2020	-1.2	-2.4	6
	19.3.2020	-0.9	-1.6	6

The third measured negative temperature was March 25, respectively -0.2°C with a duration of three hours. At that time, the ‘Ferlino’ variety was in the full flowering phase BBCH63-65, and the ‘Laskava’, ‘Puldin’ and ‘Redhaven’ varieties were in the BBCH67 petal fall phase. All other varieties and elites were located between the two phenological phases.

The last measured negative temperature for 2019 was on March 29 with an average negative temperature of -0.8°C for five hours and the lowest reported -1.7°C. On this date, only ‘Elite 4-22’ was in the phenological phase of petal fall BBCH 67. All others were between the same phenological phase and the formation of BBCH69.

In 2020, the first negative temperature was recorded on 16 March, with the lowest being -2.6°C and the average -1.2°C for six hours. At that time, the ‘Laskino’ variety was in the phenological phase BBCH57 of the beginning of the display of petals. The variety ‘Evmolpia’ and ‘Elite 7-59’ were in the next phase of development BBCH59 - mass display of petals. ‘Ferlino’ and ‘Puldin’ were at the beginning of flowering BBCH61-62, and the ‘Filina’ variety was in full flowering BBCH 63-65.

The next reported temperature was also the lowest: -4.9 °C with an average temperature of -2.3°C for ten hours on March 17. At this time, the ‘Redhaven’ variety was at the beginning of flowering BBCH 61-62. Variety ‘Flavia’ and ‘Elite 91-23’, ‘Elite 19-78’ were in full flowering BBCH63-65.

The third reported negative temperature was on March 18 with an average value of -1.2°C with a duration of action of six hours and the lowest reported -2.4°C. This date coincides with the beginning of flowering BBCH61-62 of ‘Lascava’ and ‘Maycrest’ and ‘Elite 7-59’ and full flowering BBCH63-65 of ‘Puldin’. The last negative temperature was reported on March 19, which was also the lowest -1.6°C with an average value of -0.9°C for six hours. Only the ‘Redhaven’ variety is in the full flowering phase of BBCH 63-65. Due to the faster phenological development in 2020, the cause damage was greater.

The IBM Statistics SPSS 24 statistical software product (Landau & Everitt, 2004) was used for the mathematical data processing, as well as the tools provided by MicroSoft Excel.

RESULTS AND DISCUSSIONS

The phenological development of peach varieties and elites in 2019 (Table 2) and 2020 (Table 3) varies due to the difference in temperatures. In 2019, the development of flower buds began in March and in 2020 it began in February. Negative temperatures in 2019 do not cause serious damage, as they do not coincide with the sensitive phases of development and were not too low. In the next year the reported temperature was significantly lower and with a longer effect. It coincided with the development of fruit buds, and therefore the damage was greater.

To establish similarities in the degree of frost in 2019 and 2020 between the studied peach varieties, a hierarchical cluster analysis was applied. The result of the performed clustering was presented by a dendrogram in Figure 1.

Table 2. Phenological development of peach varieties and elites for 2019

Name	A	B	C	D	E	F	G	H	I	J
Ferlino	8.03	12.03	16.03	18.03	20.03	25.03	28.03	4.04	27.07	28.08
Lascava	6.03	10.03	14.03	16.03	19.03	23.03	25.03	3.04	30.07	9.08
Evmolpia	7.03	11.03	15.03	17.03	20.03	24.03	26.03	4.04	4.09	16.09
Puldin	6.03	10.03	14.03	16.03	19.03	23.03	25.03	3.04	15.07	29.07
Filina	6.03	10.03	14.03	16.03	18.03	22.03	24.03	2.04	29.05	18.06
Flavia	4.03	8.03	12.03	14.03	17.03	21.03	23.03	1.04	29.05	19.06
Maycrest	6.03	10.03	14.03	16.03	18.03	22.03	24.03	2.04	29.05	18.06
Lascino	8.03	12.03	16.03	19.03	22.03	26.03	30.03	5.04	27.07	26.08
Redhaven	6.03	10.03	14.03	16.03	19.03	23.03	25.03	2.04	3.07	23.07
El. 7-59	7.03	11.03	15.03	18.03	20.03	24.03	27.03	3.04	29.07	26.08
El. 4-22	7.03	10.03	15.03	19.03	22.03	26.03	29.03	6.04	2.08	4.09
El. 91-23	7.03	11.03	15.03	18.03	21.03	24.03	27.03	3.04	26.07	25.08
El. 19-77	6.03	11.03	15.03	17.03	20.03	24.03	26.03	1.04	28.05	29.06
El. 19-78	6.03	10.03	14.03	16.03	18.03	22.03	24.03	2.04	20.06	1.07

Table 3. Phenological development of peach varieties and elites for 2020

Name	A	B	C	D	E	F	G	H	I	J
Ferlino	18.02	7.03	9.03	12.03	16.03	21.03	28.03	6.04	1.08	25.08
Lascava	16.02	4.03	6.03	14.03	18.03	23.03	31.03	7.04	13.07	5.08
Evmolpia	19.02	9.03	14.03	16.03	20.03	30.03	6.04	15.04	14.08	15.09
Puldin	15.02	7.03	9.03	13.03	16.03	18.03	27.03	7.04	8.06	31.07
Filina	16.02	4.03	9.03	12.03	14.03	16.03	24.03	30.03	5.06	20.06
Flavia	16.02	3.03	10.03	13.03	15.03	17.03	25.03	31.03	5.06	19.06
Maycrest	18.02	3.03	12.03	14.03	18.03	25.03	30.03	8.04	10.06	22.06
Lascino	18.02	10.03	16.03	20.03	27.03	7.04	14.04	19.04	31.07	31,08
Redhaven	17.02	10.03	13.03	15.03	17.03	19.03	26.03	7.04	10.07	30.07
El. 7-59	17.02	8.03	12.03	16.03	18.03	22.03	28.03	8.04	10.07	24,08
El. 4-22	15.02	4.03	7.03	11.03	13.03	16.03	28.03	6.04	28.07	30.08
El. 91-23	16.02	2.03	6.03	11.03	13.03	17.03	23.03	29.03	02.08	27.08
El. 19-77	16.02	3.03	7.03	12.03	14.03	16.03	26.03	31.03	5.06	20.06
El. 19-78	16.02	4.03	7.03	12.03	14.03	17.03	27.03	31.03	7.06	24.06

Legend for Table 2 and Table 3: A-Swelling of the buds BBCH-51, B-Greening of the tip BBCH-54, C-Start of petal display BBCH-57, D-Mass display of petals BBCH-59, E-Start of flowering BBCH- 61-62, E-Full flowering BBCH-63-65, G-Falling of petals BBCH-67, H-Formation of knot BBCH-69, I-Beginning of pigmentation BBCH-85, J-Full maturity BBCH- 89.

The studied varieties were grouped into four clusters. The first consisted of El. 4-22, El. 91-23, El. 7-59, as well as Maycrest, Lascava, Filina, Redhaven and Flavia, which showed higher resistance to low temperatures in 2019 and were more unstable in 2020 The second cluster included Laskino, Elite 19-77 and Evmolpia, which in both years of study were relatively resistant to cold. Ferlino and Puldin form a third group due to the high degree of sensitivity to low temperatures in both 2019 and 2020.

Elite 19-78 formed a separate cluster, joining the others at the maximum Euclidean distance, due to the high degree of frost in both years of study.

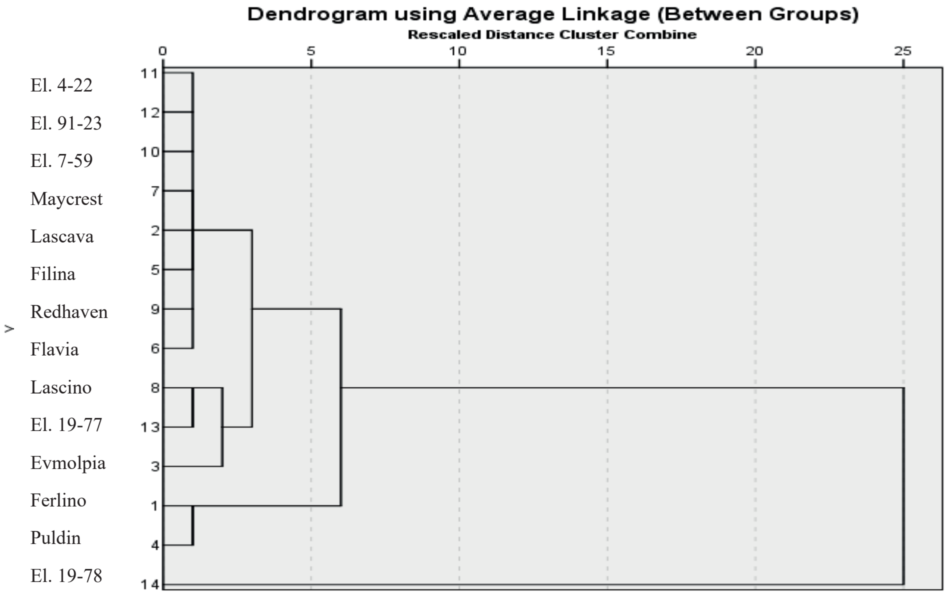

Figure 1. Grouping of peach varieties according to the degree of frost during the period 2019-2020

As a result of the applied single-factor analysis of variance on peaches, it was found that in 2019 ‘Elite 19-78’ had the highest percentage of frost (98.33%), followed by ‘Ferlino’, but much more resistant to low temperatures (50.67%) (Table 4). It has been proven that ‘Evmolpia’, ‘Filina’, ‘Flavia’, ‘Redhaven’ and ‘Elite 19-77’ do not have frozen blossoms. The

results in 2020 were significantly different. The most resistant to low temperatures varieties in 2019 were found to be among the most affected in 2020 (Figure 2). These were ‘Ferlino’ (92%), ‘Puldin’ (99%), ‘Filina’ (96%), ‘Flavia’ (92%), ‘Maycrest’ (98.67%), ‘Redhaven’ (99.67%), ‘Elite 7-59’ (92%) , ‘Elite 4-22’ (94.67%), ‘Elite 91-23’ (96.33%), ‘Elite 19-78’ (93%).
From the graphic image of Figure 2 it followed that in all varieties, except Elite 19-78, a significant increase in the percentage of frozen blossoms were demonstrated. Only with the specified elite the tendency is to decrease, but the same stands out as the most susceptible to the negative influences of low temperatures, which makes it unattractive for selection activities. Damage from negative temperatures on blossoms and pistil were presented in Figure 3. Blossom thinning and fruit thinning to moderate crop densities can influence the cold tolerance of peach flower buds in late winter (Byers & Marini, 1994). Temperatures of −30°C or lower may kill the tender fruit trees and −25°C may damage the buds in winter, although late spring frosts during bloom reduce production more frequently (Brown & Blackburn, 1987).

Table 4. Comparative assessment and analysis of variance of peach varieties according to the degree of frost and Duncan's test for evaluation of differences, a, b, c,… - degrees of significance of differences at level α≤0.05

Name	Degree of frost - 2019 (%)	Degree of frost - 2020 (%)
Ferlino	50.67^{b}	92.00^{bc}
Lascava	12.33^{d}	88.00^{c}
Evmolpia	0.00^{f}	59.00^{e}
Puldin	36.33^{c}	99.00^{ab}
Filina	0.00^{f}	96.33^{ab}
Flavia	0.00^{f}	92.00^{bc}
Maycrest	13.00^{d}	98.67^{ab}
Lascino	9.00^{e}	74.67^{d}
Redhaven	0.00^{f}	99.67^{a}
El. 7-59	13.67^{d}	92.00^{bc}
El. 4-22	15.33^{d}	94.67^{abc}
El. 91-23	14.67^{d}	96.33^{ab}
El. 19-77	0.00^{f}	77.00^{d}
El. 19-78	98.33^{a}	93.00^{bc}
SS	28927.81	5212.40
Df	13	13
MS	2225.216	400.954
F-test	584.119	26.730
Sig.	0.000	0.000

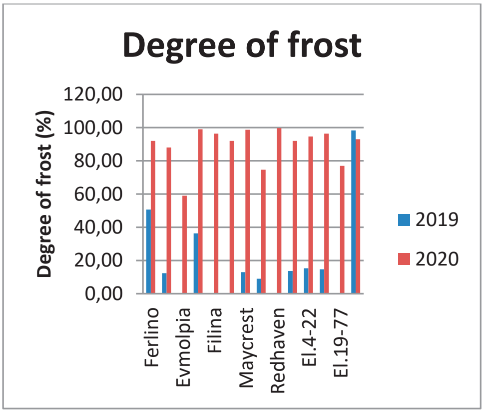

Figure 2. Change in the degree of frost in 2019 and 2020 in peaches

Figure 3. Damage from negative temperatures on blossoms and pistil

CONCLUSIONS

In 2019, ‘Evmolpia’, ‘Filina’, ‘Flavia’, ‘Redhaven’ and ‘Elite 19-77’ were the most cold-resistant varieties, and ‘Elite 19-78’ was the most sensitive one. In 2020 the blossoms of ‘Ferlino’, ‘Puldin’, ‘Filina’, ‘Flavia’, ‘Maycrest’, ‘Redhaven’, ‘El. 7-59’, ‘El. 4-22’, ‘El. 91-23’, ‘El. 19-78’ were sensitive to frost, and they have an increase in the percentage of frost compared to the previous year. The phenological phase of development had a significant impact on frost during the negative spring temperatures.

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