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Temporal changes of the frequency of spring frost damages in the main fruit growing regions in Western Hungary and in East Hungary

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Summary: Most of the risk in Hungarian fruit growing is the damage caused by late spring frosts. The frequency of late frosts seems to increase nowadays. The aim of the study was to check this contention: what is the real probability of the damages. Based on earlier experiences, the physiological LT50 function has been elaborated for new fruit varieties, which are eligible to moderate the danger when being threatened by frost. By means of this technique, the probability of freezing is distinguished between frost susceptible, frost resistant and medium frost resistant fruit species and varieties around their blooming time. The degree of frost damage depends on the duration and severity of the low temperature and not at least on the frost tolerance of the plant. For that purpose, the frequencies of frost damages were studied at two Transdanubian and two Trans-Tisza fruit growing sites by means of a meteorological database for the 60-year-long period 1951–2010. Being aware of the LT50 values changing during the phonological phases of the fruit trees from budding, bloom, fruit set and fruit growth, the number and date of critical (frosty) days could be settled. An important role is attributed to the orographic relief and the height above the sea level of the site, as 20–30 m differences and expositions may become decisive within the same plantation. The spatial distribution of damages is also dependent on the air circulations within the Carpathian basin. At the southern and northern borders of the country, especially valley bottoms represent additional risks of frost. Most spring frost damages are experienced in April 20–22, and cause heavy damages by temperature minima between – 3°C and – 6°C. The severity of damage depends largely on the temperature of the preceding few days. The earlier bloom the heavier damage is expected. The study is emphasising the importance of the varieties. Frost tolerance of some varieties may lower the risk of spring frosts by 40–50%, as experienced on the plantations. The quantification of the risks based on data raised during the last years will be suitable to define the security of yields of each growing site successfully.

Key words: spring frost damage, frost-susceptible, medium tolerant and frost tolerant apricot and peach varieties, probability of suffering frost

Introduction, survey of the literature

Among the climatic risks of horticultural production, the spring frost damages are the most important, consequently its quantification is highly justified. The severity of the damage claims a physiological approach by the LT_{50} function. The present study attempts the use of the function to distinguish between frost-susceptible, medium tolerant and frost tolerant apricot and peach varieties. The tests of measuring the severity of spring frost damages should be extended also to other fruit species. Apricot and peach are indeed relatively susceptible fruit species; therefore the experiments are initiated with those. Two Transdanubian and other two Trans-Tisza growing sites have been selected for the meteorological study, how we could calculate the probability of the damage at least on the 50% level. As by knowing the frequency of climatic risks would help to determine the risks of production.

The growing sites and varieties of peach and apricot plantations have been thoroughly elaborated by *Timon* (2000), *Zayan (1981)* and *Salary (2001)*.

Earlier studies proved that the most afflicted period is between April 11 and 15 almost on all growing sites (*Liatos* et al, 2005a).

The probability of frost damage was 12–14% on almost all growing sites: Martial, Szeged–Szatymaz and around the Lake Balaton. At Szeged–Szatymaz, in the following period (April 16–20) the risk was still about 10 %.

During a later period, April 26–30 and May 1–5, the threat is 2–4% at the Mátra–Bükkalja region only.

Earlier, it was stated that at Mátra-Bükkalja the risk was double as severe as around Buda during the period April 11–20.

The dates of bloom become later in south-north direction. At Mecsekalja (south), the bloom is earlier by 8 days than at Buda, and 12 days earlier than at Mátraalja. The bloom in the region around the Lake Balaton was 4 days later than at Mecsakalja. Based on the known data, we could calculate the frequency of the risk for the regions each. The highest probability of frost was found at Mátra-Bükkalja, followed by Buda environment, then the Danube–Tisza and Pest–Gödöllő regions. The least afflicted was Mecsekalja region in the south (*Lakatos et al.,* 2006a) by frosts during the bloom period.

Earlier results proved that during the period April 11–20 the risk of damage is about six times higher at Szeged–Szatymaz and the Balaton region than at Mecsekalja (*Lakatos et al.* 2005 b.)

It turned out that in the region Mátra–Bükkalja, the dates of bloom were delayed, which diminished the risk of frost damage of this particular period related to the total spring frost damage. In the regions Mecsekalja and Duna–Tisza köze, no significant relation has been found between the date of bloom and the frost damages, whereas in the regions Pest-Gödöllő and Buda, the probability of damage was lower by 2–5% if the dates of bloom have been considered (*Lakatos et al.,* 2006c).

A detailed analysis was initiated to check the effect of delayed blooming dates on the probability of frost damage in several regions of fruit growing of Hungary. In some cases, the damage was diminished by 0–20% when the bloom started 5 days later (*Lakatos et al.,* 2006b). Most reduction of damage was found in Mecsekalja, whereas the less in the region of Buda. A 10 day long delay of bloom diminished the damage by 37–85% in other regions. If a global change of the climate will occur, the most reduction of damage is expected in the Duna–Tisza köze and Pest–Gödöllő regions, whereas the less reduction in the Mecsekalja region.

Earlier studies stated that during the last 50 years, the frequency of spring frost damages changed on the main fruit growing regions of the country. The decennium after 1870 seems to be favourable from the point of view of risks due to spring frosts (*Szabó et al.,* 2006). During the last 60 year long period, most damages due to frosts (winter- and spring frosts together) occurred at highest frequencies in the decennium of 1960-es. Considering the means of all growing regions, a general increment of damages since the 1970-es up to now is documented.

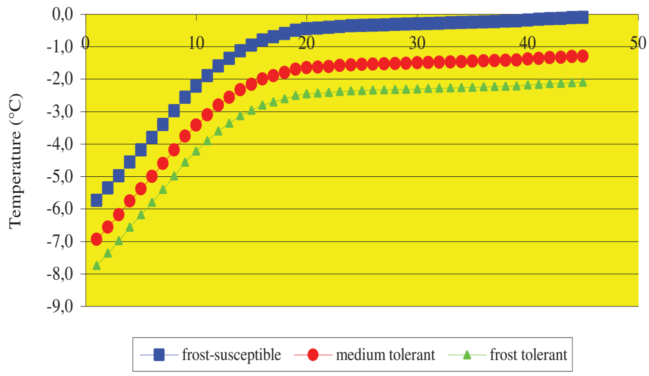

Figure 1 – The physiological LT50 function applied to apricot and peach varieties of different degrees of susceptibility for a period between April 1 and May 15.

Material and method

For the purpose to quantify and express the measure of damage caused by frost we applied the LT_{50} function (the temperature causing 50% lethality). We developed the function to be applied to varieties of different susceptibility *(Figure 1)*.

The frost susceptibility in the spring could be described by the function as a polynomial of the third grade. The formulae are applied for the three types of susceptibility or tolerance: susceptible, medium tolerant and tolerant:

$$y_{\text{frost susceptible}} = 0.0002x^3 - 0.0193x^2 + 0.612x - 6.6079$$

$$y_{\text{medium tolerant}} = 0.0002x^3 - 0.0193x^2 + 0.612x - 7.8079$$

$$y_{\text{tolerant}} = 0.0002x^3 - 0.0193x^2 + 0.612x - 8.6079$$

By means that those formulae will express the frequencies of critical temperatures measured at 2 m height over the soil level. It was supposed that the curves presented could be applied to all main apricot and peach varietes and growing regions.

The changes of cold tolerance in buds and reproductive organs were observed during the rest period by *Szalay et al.* (2000) and *Szalay* (2001), and they compared the methods developed to explore the chilling requirement of plants. Presently, we applied the method to the blooming period.

In this case, LT_{50} is a value expressing the temperature, which causes 50 % death (lethality) of the plant organs (buds, flowers or fruit primordia).

The method of the analysis has been applies first for the rest period to find the LT_{50} value by *Szabó et al.* 2001, *Szalay et al.* 2000. Authors cited worked at three growing sites (Siófok, Szigetcsép, Pomáz) during the period 1995–2004, and observed 9 peach varieties (Venus, Red June, Babygold6, Redhaven, Mayfire, Caldesi, Early Redhaven, Champion and Piroska) and 5 apricots (Ceglédi bíbor, Ceglédi óriás, Gönci magyar kajszi, Mandula kajszi, Bergeron) as for their frost tolerance. We supposed that frost tolerance observed in winter will be related to tolerance of the flowers in spring. Cold susceptible varieties during the rest period will be susceptible in the bloom period too to low temperatures.

The database of four growing regions over the period 1951–2010 has been utilised:

– **Debrecen**
– **Nagykanizsa**
– **Siófok**
– **Újfehértó**

where the daily minimum temperatures were collected. The data of the OMSZ (Countrywide Meteorological Service) have been processed with variance analysis, the curves of regression expressing trends fitted. The computations were performed by the Windows Escel program.

The LT_{50} function applied for the blooming period was the base of finding the frequencies of spring frosts and the expected damages on apricots and peaches of different frost tolerance. If we find data fitting into the LT_{50} function or even lower values during the critical period, the frost damage could be predicted.

Results

Considering the distribution of the absolute daily minimum temperatures during the spring season, the zonal character of the phenomenon could be observed *(Figure 2)*. The zones mean in this case a drastic drop of temperatures moving along a SW-NE axis. The zonal distribution arose by circulations, with other words around action centres. Due to this zonal character, we will find a steep spatial temperature gradient characteristic for that season. Between the two loci Kecskemét and Balassagyarmat (Centre and North Hungary) the difference of temperatures attained more than 9 °C. The lowest minima occurred over the hills of Zala county and the eastern of part of the Little Plain. The highest (less cold) absolute minima were measured east to the Tisza river and in SE Transdanubia, around Villány during the last 60 years.

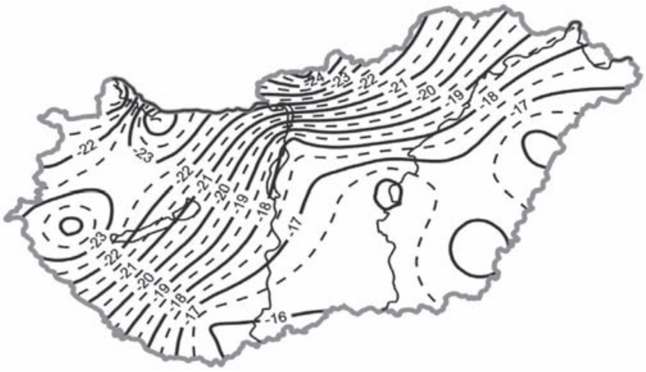

Figure 2 – The distribution of the absolute minimum temperatures in spring according to the data of 16 stations over the country during the 60 year long period 1951–2010

The temporal distribution of temperature minima is important information for the strategy of fruit growing policy on the long run. The changes registered during two decennia suggest that the absolute minima dropped except in the region of Nagykanizsa (SW corner). *(Figure 3)*. During the period 1970–1990, around blooming time no frosty, i.e. less than –5 °C temperatures occurred. During the last decennium, especially in 2007, at several points of the country, the temperature dropped two times below 0 °C: April 23 and May 2. The spring of 2003 also surprised the fruit growers at April 9 until –6°C over several regions. Our near past excels already with several cases when frosts occurred during bloom of fruit trees, as in 2011 and 2012. In spite of the global warming up, there is no reason to believe that it was the last frosty spring, on the contrary, the prognosis promises extreme episodes becoming more frequent including frosts of – 6–7°C at dawn in April and May.

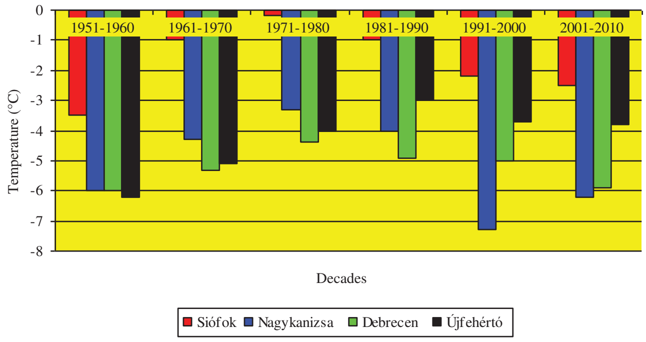

Figure 3 – The occurrence of absolute minimum temperatures during the blooming season in four regions, as appearing in every decennium over the 60 year long period: 1951–2010

If we consider the mean of minimum temperatures during the blooming periods and its changes at four fruit growing periods over the 6 decennia, we may state:

Until the end of the 1980-es, the two East-Hungarian regions proved to be the most cold *(Figure 4)*. Beginning with the 1990-es, the region of Nagykanizsa did not warm up as the other regions observed. The station of Siófok excelled with the highest mean temperatures during the rest period. Over the 60 year long period, the only decennium of the 1960-es produced negative mean temperatures during the rest period of trees. The higher and more equalised minimum temperatures are due to the heating effect of the Lake.

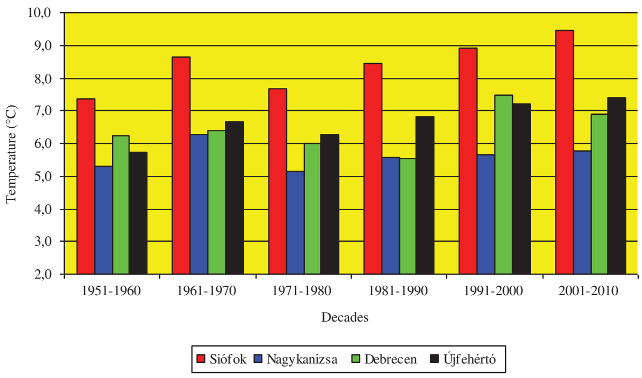

Figure 4 – The 10-year-mean temperatures of the spring season (April 1 – May 15) in four fruit growing regions over the period 1951–2010.

The estimation of risks caused by spring frosts (blooming period) is approached by the registration of the daily variation of temperature. The large amplitude of the variation is due mainly to the cooling down during the night hours. Temperatures below the freezing point are dangerous for the fruit grower let alone their short duration. Comparing the variation of temperature at the four growing sites *(Figure 5),* we could observe that at Siófok and Újfehértó the daily variation of temperature was the same over 60 years, however, at Nagykanizsa, beginning with the 1970-es the daily variation increased from 11.5 °C to 13.4 °C. It means that the frequency of frost increased too in this region.

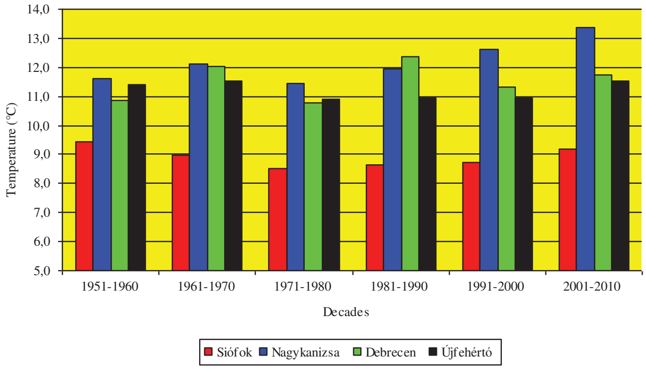

Figure 5 – The mean daily variation of 10 year long periods during the blooming season (April 1 – May 15) in four fruit growing regions over 60 years: 1951–2010

Frost damages were analysed on apricot and peach trees representing frost susceptible, medium tolerant and frost tolerant varieties. As the heavier damage appeared on the susceptible apricot and peach varieties, the figures (pictures) presented refer to those.

Fruit growers of the Siófok region reported every year damages caused by spring frosts and spend large sums to invest for frost protection. The registered data over 60 years of the meteorological service (OMSZ) do not corroborate the complaints. However, the station is close to the Lake shore, consequently reflects the temperature compensating effect of water. The daily warming up as well as the cooling of nights is largely moderated. This is also the cause of lower frequencies of frost damages in the blooming period. As presented on *Figure 6,* the damage of susceptible apricot and peach varieties was less than 2%. Between Aprils 1 and May 15, in the 8 day period, the risk of damage was 1.7%. In medium tolerant varieties, a single day, April 20, meant 1.7% risk, whereas tolerant varieties are not at all threatened by frost. Over the last 60 years any noteworthy frost damage was reported after May 6 at Siófok.

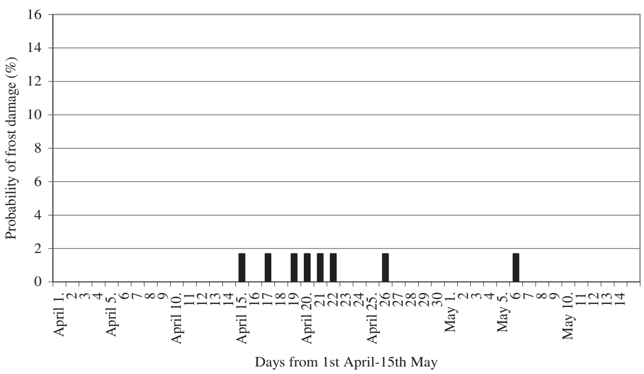

Figure 6 – Probability (%) of noteworthy frost damage during the blooming season on susceptible apricot and peach varieties at Siófok during 1951–2010

At the Debrecen, most of the frost damages are reported during the period April 18–21, and the risks was 9.8% *(Figure 7).* The distribution of probabilities of frost damages means higher risks in the period April 10–20 than in April 20-30. The number of days representing higher risks of damages, more than 6%, was 11 in the case of susceptible apricot and peach varieties. During the blooming period, the probability of suffering frost was nearly 3%, and it occurred 22 times (over 60 years).

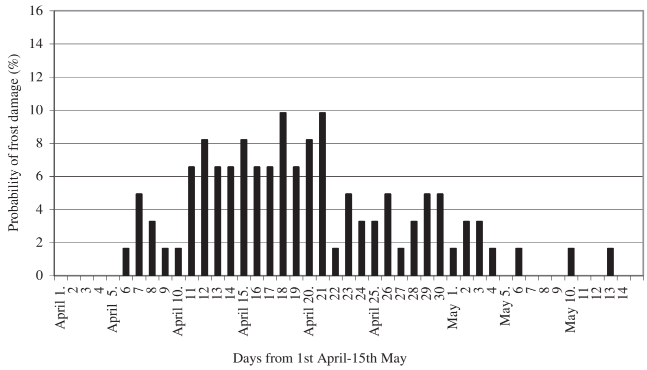

Figure 7 – Probability of suffering frost during blooming in susceptible apricot and peach varieties (Debrecen-Pallag, 1951–2010)

At Nagykanizsa, the occurrence of frost damage during the blooming period attained the highest probability among the four growing sites examined. The distribution of the probabilities was symmetrical, which means that it is equal during the April 10–20 as well as in April 20-30. The number of days representing 6% or more risks of damage was 15 *(Figure 8),* i.e. more than at Deberecen. During the 60 years, it occurred 27 times and the damage meant 3% risks.

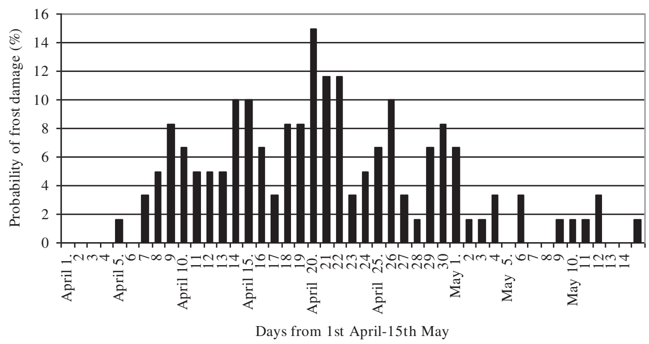

Figure 8 – Probability of suffering frost during blooming in susceptible apricot and peach varieties (Nagykanizsa 1951–2010)

At Újfehértó, though not far from Deberecen, there are temporal differences in frequencies as well as in the severity of frosts between the two regions. The distribution of probabilities is also biased, as frosts are more probable between April 9–19 than between April 20–30. During the spring there are 3 days with risks with more than 6%, and over 60 years, it occurred 16 times that frost caused 3% damage *(Figure 9).*

Our studies proved that the damages registered were rather different if we consider frost tolerant fruit species instead of susceptible ones. *Table 1* shows the difference between the damage in susceptible and medium tolerant apricot and peach varieties at Siófok, if the damage may attain 1.7 % as a maximum. In frost tolerant varieties any damage is expected according to a period of many years, where the probability of frosts was nearly 5%.

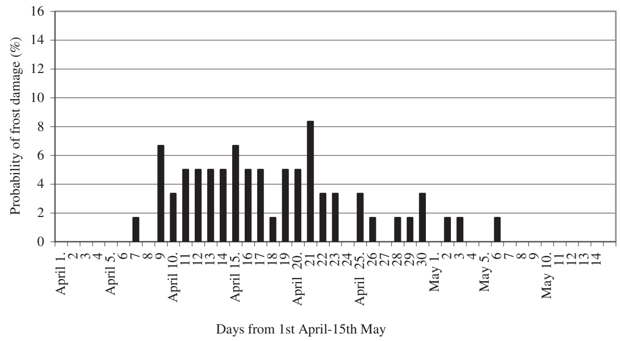

Figure 9 – Probability of suffering frost during blooming in susceptible apricot and peach varieties (Újfehértó, 1951–2010)

Table 1 – Occurrence of frost damage of increasing severity in apricot and peach varieties of different susceptibility during the rest period (Siófok, 1951–2010)

		Apricot and peach varieties		
		frost susceptible	**medium tolerant**	**frost resistant**
Siófok	3% frost damage (day)	0	0	0
Siófok	6% frost damage (day)	0	0	0
Siófok	max frost damage (%)	1.7	1.7	0.0

In the Debrecen region, the probability of damage caused by frost was difference between susceptible and tolerant varieties *(Table 2)*. In susceptible apricot and peach varieties, frost damage occurred during the blooming season over 22 days as a mean of many years, which means a risk of 3% at least, whereas in tolerant varieties, 4 days only were observed with a probability of 3% frost damage.

Table 2 – Occurrence of frost damage of increasing severity in apricot and peach varieties of different susceptibility during the rest period (Debrecen, 1951–2010)

		Apricot and peach varieties		
		frost susceptible	**frost susceptible**	**frost susceptible**
Debrecen	3% frost damage (day)	22	8	4
Debrecen	6% frost damage (day)	11	2	0
Debrecen	max frost damage (%)	9.8	6.6	4.9

As stated above, the highest probability of spring frosts was found in the region of Nagykanizsa. On frost susceptible varieties of apricots and peaches are threatened during 27 days by frosts, which cause 3% risks of damage as a mean of many years, whereas in the case of frost tolerant varieties, only 6 days are exposed to cause 3% damage during blooming time *(Table 3)*.

In the region of Újfehértó, the incidents of spring frosts are more favourable than in Debrecen. The afflicted period during bloom of fruit trees is shorter, as a mean of many years 16 days when 3% risk of damage is expected for susceptible apricot and peach varieties, and 2 days only for tolerant apricot and peach varieties *(Table 4)*.

Table 3 – Occurrence of frost damage of increasing severity in apricot and peach varieties of different susceptibility during the rest period (Nagykanizsa, 1951–2010)

		Apricot and peach varieties		
		frost susceptible	**frost susceptible**	**frost susceptible**
Nagykanizsa	3% frost damage (day)	27	12	6
Nagykanizsa	6% frost damage (day)	15	3	0
Nagykanizsa	max frost damage (%)	15.0	6.7	5.0

Table 4 – Occurrence of frost damage of increasing severity in apricot and peach varieties of different susceptibility during the rest period (Újfehértó, 1951-2010)

		Apricot and peach varieties		
		frost susceptible	**frost susceptible**	**frost susceptible**
Újfehértó	3% frost damage (day)	16	5	2
Újfehértó	6% frost damage (day)	3	0	0
Újfehértó	max frost damage (%)	8.3	3.3	3.3

If we consider the meteorological parameters as means of 10 year long periods concentrating on cases, when the damage attained 50% or more severity, we may conclude:

The growing of frost susceptible apricot and peach varieties is less risky at the Siófok among the four main fruit growing regions examined in Hungary. A significant frost occurs at low frequency, i.e. once per 10 years *(Table 5)*. We have to take into account the temperature-moderating effect of the Lake Balaton. The second best site is the region of Újfehértó, being less risky than Debrecen. At Újfehértó, 4 years out of 10 are afflicted by frosts around blooming time, whereas at Debrecen every second year is marked by risks.

For frost susceptible varieties, the region of Nagykanizsa means the highest risks of frost damage being probable in 7 years out of 10.

For medium tolerant apricot and peach varieties, the region of Siófok meant the most favourable growing site out of the 4 regions examined. Over the 60 year old period, it occurred but once when significant frost damages occurred.

The region of Újfehértó proved also for the medium tolerant apricot and peach varieties as the next most favourable regarding the climatic conditions. Here the risky years were 1 out of 5 *(Table 6)*. At Debrecen, 3-4 years out of 10 are afflicted by spring frosts.

Table 5 – The frequency of years expecting frost damages during the 60 year long period examined and their distribution according to decennia (1951–2010)

Frost susceptible varieties				
	Apricots and peaches			
Region	Debrecen	Nagykanizsa	Siófok	Újfehértó
1951–1960	5	8	2	7
1961–1970	6	5	0	3
1971–1980	6	9	0	4
1981–1990	7	6	0	4
1991-–2000	4	8	1	4
2001-2010	3	6	0	3
means	5.2	7.0	0.5	4.2

Table 6 – The frequency of significant spring frost damages and its change for medium tolerant apricot and peach varieties (1951-2010)

Medium susceptible				
	apricot and peach varieties			
	Debrecen	Nagykanizsa	Siófok	Újfehértó
1951–1960	3	7	1	4
1961–1970	3	4	0	1
1971–1980	4	5	0	1
1981–1990	6	4	0	1
1991–2000	2	3	0	4
2001–2010	3	4	0	1
means	3.5	4.5	0.2	2.0

For medium tolerant varieties, in the region Nagykanizsa, the spring frosts mean the highest risks. The database of the 60 year long period witnessed spring frosts every second year.

For cold tolerant apricot varieties, the region of Siófok if the most favourable out of the four growing sites examined. Over the 60 year long period, no significant frost damage has been observed on frost tolerant fruit varieties *(Table 7).* At Újfehértó once out of 10 years, frost damage was found during bloom. At Debrecen, every fifth year has chances to suffer spring frost damage.

Table 7 – The frequency of years expecting frost damages on frost tolerant apricot and peach varieties during the 60 year long period examined and their distribution according to decennia (1951–2010)

Frost tolerant				
	apricot and peach varieties			
	Debrecen	Nagykanizsa	Siófok	Újfehértó
1951–1960	2	4	0	3
1961–1970	1	2	0	1
1971–1980	2	1	0	0
1981–1990	4	3	0	0
1991–2000	1	2	0	2
2001–2010	1	4	0	0
mean	1.8	2.7	0.0	1.0

For cold telerant apricot and peach varieties, the highest risk of spring frost damage means 3 years out of 10 at Nagykanizsa.

Conclusions

The global weather forecasts predicted significant warming up in the springtime for the second part of our century. The raising mean temperature alone does not guarantee the prevention of spring frosts. Conditions of the accumulation of cold air are a cloudless sky, lack of air circulation and low relative air humidity because heat is lost by radiation and the cold air accumulates on the soil surface due to its specific gravity. During the last two years, several frosts occurred, perhaps not the last.

By means of the values of LT_{50} the sums of temperature could be traced daily and the end of the rest period calculated for the given fruit variety as the term when the cold resistance changes (declines).

The method is, however, not suitable to estimate the damage numerically. The development of absolute minima cannot be predicted.

Our results may help to calculate risks of fruit production taking into account the risks of the growing site as well as the susceptibility or tolerance of the variety. Recommendations of varieties for the growing sites could be based on the presented results. The risks of fruit production should be utilised in planning and policy of rural development.

Acknowledgement

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