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EGYETEM

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Doctoral (PhD) thesis

Evaulation of stress tolerance, phenological characteristics and fruit quality parameters, of peach cultivars in gene bank

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1. INTRODUCTION

Peach is one of the most essential produced fruit in Hungary. The fruit is suitable for both fresh market and industrial producers, therefore it is quite favoured by the consumers. The efficiency of production is strongly influenced by the chosen peach cultivars. New cultivars are appearing constantly due to work of breeders. Preceding the greater plantations all characteristics are required to be examined which influence their ecological adaptation ability, productivity, fruit quality and market value. Research of cultivar is practically essential in addition, the exact determination of genotype morphological and phonological features is important considering basic research. Department of Pomology has been dealing with the detailed examination of peach cultivars for decades. There are several research methods available and the headquarters can be located at the gene bank of Soroksár.The results of the three-year research work presented in the thesis occurred in this research program. The different cultivars used in the areas were chosen according to previous tests.

Frost hardiness is a type of abiotic stress. Changing of the frost hardiness of flower buds was determined by artificial freezing method during winter dormancy. The artificial freezing method was devised by Department of Pomology. There are several biotic stresses of peach. The most dangerous is the fungi leaf curl (*Taphrina deformans),* which can cause big financial damage. Susceptibility of peach cultivar to leaf curl was evaluated in gene bank. Fruit quality parameters were also evaluated and compared for two consecutive years on peach cultivars in three ripening stages. Size and weight and also physical and chemical characters were determined during ripening time.

2. RESEARCH AIMS

The aims of our research work were to evaluate the frost hardiness and fruit quality parameters also relationship among biological ripeness characters on peach cultivars coming from abroad in the Hungarian climate. Due to our results, it could be determined, that a given cultivar can be grown in Hungary or not. Control cultivars adopted from abroad have been growing for decades in Hungary. Both traditional and latest research methods were conducted in field and laboratory.

Details:

1. Determining frost hardiness of peach cultivars by artificial freezing method.
2. Proving the effect of the agricultural year on the frost hardiness of peach cultivars by statistical methods.
3. Categorizing peach cultivars based on frost hardiness.
4. Categorizing peach cultivars based on susceptibility to leaf curl (*Tapfrina deformans* L.)
5. Evaluation and determination of peach fruit quality parameters in different seasons.
6. Relationship between ripening stage and soluble solids content of peach cultivars.
7. Relationship between flesh firmness and soluble solids content of peach cultivars.
8. Relationship between titratable acidity and soluble solids content of peach cultivars.

Our intention was to widen our knowledge with new research results, on the fields of yield stability and market value of peach cultivars.

3. MATERIALS AND METHODS

3.1. Place, time and environment of research

Examinations were conducted between the years of 2012 and 2016 during winter dormancy also between the years of 2014 and 2015 ripening seasons, furthermore May of 2011, 2013 and 2018 in peach gene bank located at Research and Experimental Farm of Szent István University. Gene bank has 82 peach cultivars on 0,3 ha.

The trees were grafted onto peach seedling rootstocks ('C 2630') and trained to a slender spindle shape with a spacing of 4x2 m. Integrated plant protection was applied (Szalay at al. 2010).

Environmental characteristics of peach gene bank are shown by table 1. (Németh 2012, Stefanovits 1966, Földvári 1966, Bacsó 1959).

1. table Environmental characteristics of peach gene bank at SZIE, Department of pomology

1.	Location	Soroksár, Budapest
2.	Humus content	0,5-1,4%
3.	pH content	7,6-8,1
4.	lime content	2%
5.	Annual average temperature	10-11°C
6.	Annual precipitation	550-600 mm
7.	Main wind direction	NW
8.	Annual hours of sunshine	2000-2050

3.2. Method of sampling and examination

The original aim of our thesis placedboitic resistance, abiotic resistance and fruit quality parameters in order to examine whatever peach cultivars might be available. However, there were several kinds of difficulties to carry out this aim. Investigation of susceptibility to leaf curl (*Tapfrina deformans* L.) was easily conducted on many peach cultivars without any problems. Investigations of fruit quality parameters were also conducted on several peach cultivars, but serious frost damage excluded a number of peach cultivars because they had less than two year results. The climate chamber (Rumed 3301) at the Department of Pomology was used by other PhD students at the same time. Further peach cultivars could not be investigated, because the climate chamber has reached the maximum capacity.

3.2.1. Frost hardiness of peach cultivars

Frost tolerance of five peach cultivars 'Venus', 'Rich Lady', 'Redhaven', 'Piroska', 'Zsoltüj' were examined from the autumn of the year 2012 until the spring of the year 2016. This requires the use of controlled climate chambers where the processes can be modeled, i.e., the temperature can be gradually changed. The frost resistance of the flower buds was tested in artificial freezing tests one to two times a month from 1 September until the trees blossomed the next spring(2012/13, 2013/14, 2014/15, 2015/16). At each sampling date, one branch with a length of 50 to 80 cm and bearing 50 to 70 flower buds was collected from each individual tree of a cultivar for one freezing temperature. A Rumed 3301 (Rubarth Apparate GmbH) type climate chamber was used for the experiments. During the treatment, both freezing and thawing were carried out gradually. The temperature was reduced by 2 °C/hour and the samples were kept at the desired freezing temperature for 4 hours, after which the temperature was raised by 2 °C/h. The degree of frost damage was evaluated after the buds were sliced, based on their browning. The browned tissues were considered to be damaged, while green tissues were considered to be intact. The frost tolerance was determined based on the lethal temperature to 50% plant tissue (LT_{50}) for each cultivar on every occasion. At each sampling date, the LT_{50} values (the temperature at which 50% of the flower buds were damaged) in addition LT_{20} and LT_{80} were calculated from the regression curves ordered to the percentages of bud damages of the five branches of each cultivar measured at the five freezing regimes to obtain comparable data (Szalay et al. 2010, Gu 1999). ANOVA test was carried out: Kolmogorov-Smirnov test, Levene test were accepted. F-values, t-values, R2, ß0 and ß1 were also determined for linear regression ($p<0,05$).

3.2.2. Susceptibility of peach cultivars to leaf curl

A field study was conducted during the 2011, 2013 and 2018 growing seasons to determine and compare the susceptibility of 50 peach (*Prunus persica* L. Batsch) cultivars to leaf curl due to *Taphrina deformans*, in the climatic conditions of Hungary. During each season, the peach leaf curl was estimated and cultivars were characterized according to their susceptibility. Observations (0-10) were recorded on leaves from three replicate trees of each cultivar located in the gene bank plantings at the Experimental and Research Farm of Szent István University, Department of Pomology, Soroksár, Hungary. Trees without symptoms scored 0, in addition trees showed the strongest symptoms scored 10 points. Fungicide sprays were applied to the trees during the study. The overall disease incidence values were estimated using data averaged over three years. Statistical evaluation based on ANOVA.Levene’s Test for Equality of Variances: $p<0,05$; H0 of residuals is rejected. Furthermore residuals passed the normality test.

3.2.3. Fruit quality parameters of peach cultivars

The physical and chemical characteristics of the peach samples collected on the experimental field were investigated in the analytical laboratory of the Department of Pomology in the ripening season of the years 2014 and 2015. The examined peach cultivars are shown in table 2. Peach samples were grouped visually based on colour and firmness into three different ripening categories: 70-80%, 80-90%, 90-100%. The following physical parameters were measured: fruit weight (g), three different kinds of fruit diameter (height, width, and thickness; mm) in addition, cover color (%) and colour hue (0-9). The investigated chemical parameters were as follows: flesh firmness (kg/cm^2), titratable acidity (%) and soluble solids content (Brix°). Relationship among chemical parameters of peach cultivars was also examined. Analyzing the data of the physical and chemical parameters of fruits, one-way (cultivar) ANOVA, two-way (cultivar, year) ANOVA, or multivariate ANOVA (MANOVA) and t-test were used to compare the cultivars, or the data of different years. Furthermore Games-Howell post hoc test were used. The chemical parameters measurements were compared based on the Pearson correlation coefficient (Kerékgyártó et al. 2009).

Table 2 Examined peach cultivars (Soroksár)

	Cultivar	Ripening time	Fruit quality parameters	Correlation analysis
1.	'Adriana'	3 Jul	X	X
2.	'Red Rubin'	06 Jul	X	
4.	'Early Redhaven'	11 Jul		
5.	'Diamond Bright'	11 Jul	X	X
3.	'Ambra'	14. Jul	X	X
6.	'Olimpio'	26 Jul	X	X
7.	'Incrocio Pieri'	06 Aug	X	
8.	'Zsoltüj'	24 Aug	X	X
9.	'Red Cal'	25 Aug	X	X
10.	'Padana'	25 Aug	X	X
11.	'Audust red'	28 Aug	X	
12.	'Michelini'	30 Aug	X	

4. RESULTS

4.1. Frost hardiness of flower buds of peach cultivars in winter dormancy

LT_{50}-values of five peach cultivars were determined by artificial freezing test. Table 3 shows some important characters of LT-values of investigated peach cultivars. Peach cultivars with high frost tolerance can be modeled by linear function. Frost sensitive peach cultivars can be modeled by inverse function. 'Rich Lady' with highest LT_{50} values was the most frost sensitive cultivar every year, whereas flower buds of 'Zsoltüj' with lowest LT_{50}values showed the highest frost tolerance. Differences among LT_{50}-values of the two cultivars mentioned above were between 4,4 °C and 7,5 °C during the investigated years. In other words, flower buds of 'Zsoltüj' tolerated 4,4-7,5 C cooler temperatures as flower buds of 'Rich Lady'. LT_{20} and LT_{80} values were also determined in controlled climate chamber. Flower buds of 'Rich Lady' needed less temperature drop (4,6-5,5°C) to suffer 80% of frost damage instead of 20%, than 'Zsoltüj'(6,0-8,8°C) in the investigated years.

Table 3. Maximum LT-values of five peach cultivars during four winter seasons with artificial freezing method (Soroksár, 2012-2016)

Cultivar	LT_{max}-values	2012/13 1 January 2013	2013/14 1 January 2014	2014/15 23 December 2014	2015/16 18 January 2016.
'Rich Lady'	LT_{20}	-16,7	-16,6	-14,1	-14,8
	LT_{50}	*-18,8*	*-18,7*	*-16,3*	*-17,1*
	LT_{80}	-21,6	-21,2	-19,4	-20,3
'Venus'	LT_{20}	-18,6	-17,5	-15,7	-16,4
	LT_{50}	*-20,5*	*-19,4*	*-17,7*	*-18,6*
	LT_{80}	-22,8	-21,9	-20,4	-21,5
'Redhaven'	LT_{20}	-19,7	-18,6	-17,9	-18,2
	LT_{50}	*-22,1*	*-21,0*	*-20,6*	*-21,0*
	LT_{80}	-24,5	-23,3	-23,3	-23,9
'Piroska'	LT_{20}	-20,8	-19,6	-18,9	-19,6
	LT_{50}	*-23,7*	*-22,6*	*-22,0*	*-23,8*
	LT_{80}	-26,6	-25,6	-25,1	-28,0
'Zsoltüj'	LT_{20}	-21,0	-19,9	-19,2	-20,2
	LT_{50}	*-23,9*	*-23,1*	*-22,7*	*-24,6*
	LT_{80}	-26,9	-26,2	-26,2	-29,1

LT_{50}-values of the investigated peach cultivars measured at different dates were contrasted with the weather. Frost tolerance of flower buds increased depending on year, when the temperature decreased gradually during the first half of dormancy. The frost hardiness of flower buds gradually developed during the hardening. The hardening depended on the speed of temperature drop in given season. Late temperature drop resulted more sensitive flower buds to frost. Every year, peach cultivars showed their maximum mean frost tolerance values (LT_{50}) in December and January. From January onward, the flower buds responded sensitively to warming, and the frost resistance of the buds decreased rapidly in response to the weather. Substantial differences in the frost resistance of the flower buds were thus observed between the years. There was -10,5°C in March in the season of 2012/13, which caused minimum 50% frost damage on the field, too. LT_{50} values of peach cultivars from most frost sensitive to most frost resistant every investigated year: ‘Rich Lady’, ‘Venus’, ‘Redhaven’, ‘Piroska’, ‘Zsoltüj’.

4.2. Statistical analysis of frost hardiness of examined peach cultivars

The year effect was significant (F(3;168)=20,66; p<0,001) in point of view of the mean frost tolerance values (LT_{50}) of cultivars. The effects of environmental factors influenced supremely on frost tolerance of the cultivars in September and March. The effects of genotypic differences were in endodormancy (December, January). Peach cultivars were hardening better and showed higher frost tolerance during longer and cooler winters (2012/13; 2013/14).

Based on the two-way ANOVA with blocking, it can be concluded, that no significant interaction effect could be shown between year and cultivar effects ($F_{year*cultivar}$(3;168)=0,356; p=0,98). The cultivar, however, had strongly significant effect ($F_{cultivar}$(4;168)=66,67; p<0,001). Based on Tukey post-hoc test investigated peach cultivars were grouped into three categories. (1) ‘Rich Lady’ (M=-16,200; SD=2,04) and ‘Venus’ (M=-17,141; SD=1,92) belonged to most frost sensitive category; (2) ‘Redhaven’(M=-19,259; SD=1,73) belonged to category with moderate frost tolerance; (3) ‘Piroska’ (M=-21,253; SD=1,70) and ‘Zsoltüj’ (M=-21,741; SD=1,65) belonged to categories with the highest frost tolerance. Dormant seasons during endodormancy (F_{year}(3;65)=4,749; p<0,01) were split into three categories based on Tukey post-hoc test. (1) Cultivars were the most sensitive to frost in the season 2014/15 (M=-18,035; SD=2,78);

(2) the seasons of 2013/14 and 2015/16 (M=-18,920; SD=2,64 and M=-19,352; SD=3,15) belonged to the second category; (3) peach cultivars showed their lowest mean frost tolerance values (LT_{50}) in the season of 2012/13 (M=-20,110; SD=2,37). Comparing seasons based on individual cultivars didn't show significant effect (p=0,07). Cultivar 'Redhaven'showed the less differences among maximum LT_{50} values in four seasons (2012/13: -22,1 °C and 2014/15: -20,6 °C). Cultivar 'Venus' showed the largest differences among maximum LT_{50} values in four seasons (2012/13: -20,5 °C and 2014/15: -17,7 °C). The largest difference between the most sensitive cultivar 'Rich Lady' and 'Zsoltüj' with the highest frost tolerance was in the season 2015/16 (6,1°C), and the less difference between the two cultivars mentioned above was in the season 2013/14 (4,9°C). Frost tolerance and hardening of flower buds in the endodormancy depend on the speed of external temperature drop during the ecodormancy. That's why differences were found among mean frost tolerance values (LT_{50}) of seasons.

4.3. Susceptibility of peach cultivars to leaf curl *Taphrina deformans* /Berk./ tul.

Based on one-way ANOVA, the cultivar effect in susceptibility to leaf curl was significant ($F(47;96)=10,55$; $p<0,001$). The results of three seasons were grouped into four main categories (Categories from 1 to 4: least susceptible, medium susceptible, susceptible, and most susceptible). Categories, ripening time, investigated cultivars and their origin are shown in Table 4. The most susceptible cultivars were characterized as having yellow flesh, whereas less susceptible cultivars tended to have white-fleshed fruit. The explanation of the differences between the two types could be the beginning of their vegetation. In our observations, vegetation of yellow fleshed cultivars starts later than white fleshed cultivars. That's why there are fewer chances for symptoms to appear in the warmer weather. Nectarines were more susceptible than peaches. In our observations, vegetation of peaches starts later than nectarines. That's why there are fewer chances for symptoms to appear in the warmer weather. There were no differences between European and American cultivars in susceptibility to leaf curl. The Hungarian cultivars 'Vérbarack', 'Nektár-H', 'Mariska', 'Aranycsillag' could be recommended as breeding source for leaf curl resistance in the future. Cultivars from Ukraine 'Rubinovűj-8' and 'Krümcsanyin'(TIMON 1997, 1999a,b) belonged to category 3 and 4, respectively. Other cultivars from Ukraine 'Nyikitszkij-85' and 'Orosz lapos' (flat peach) belonged to category 1. Cultivars belonging to categories 3 and 4 ripen at the end of July and beginning of September. The most susceptible cultivars ripen in August. The three most susceptible cultivars were 'Flavortop', 'Nectaross', and 'Elberta', whereas the two least susceptible cultivars were 'Vérbarack' with red flesh (originally from Hungary) and K10 ('Rikakusuimitsu'; with white flesh; originally from Japan). Neither of them showed symptoms of leaf curl.

Table 4.Ripening time and susceptibility of peach cultivars to leaf curl (Soroksár, 2011, 2013, 2018)

	Category	Cultivar	Type	Ripening time	Origin of the cultivar	Avarage inwection of leaf curl (0-10) 2011, 2013, 2018		Category	Cultivar	Type	Ripening time	Origin of the variety	Avarage inwection of leaf curl (0-10) 2011, 2013, 2018
1	Category 1	K 10	pw	Aug2d	Japán		26	Category 1	Spring Lady	py	Jul2d	USA	1,60
2		Vérbarack	pr	Sept1d	HUN	0,00	27		Springtime	pw	Jul1d	USA	1,29
3		Aranycsillag	py	Jul3d	HUN	0,50	28		Sunbeam	py	Jul2d	USA	1,00
4		Cresthaven	py	Aug3d	USA	0,50	29		Suncrest	py	Aug2d	USA	1,44
5		Early Redhaven	py	Jul2d	USA	1,08	30		Zsoltüj	ny	Aug3d	UK	0,50
6		Fusador	ny	Aug3d	USA	1,50	31	Category 2	Apolka (11/6)	ny	Aug2d	Cseh	2,33
7		Genadix 4	pw	Jul1d	FRA	0,50	32		Kraprim	pw	Jun1d	USA	3,17
8		Harko	ny	Aug2d	CAN	0,90	33		Michelini	pw	Sept1d	ITA	3,10
9		Incrocio Pieri	pw	Aug2d	ITA	0,75	34		Olimpio	nw	Jul3d	USA	2,17
10		K 16	pw	Jun3d	Kína	1,50	35		Padana	py	Sept1d	ITA	2,75
11		K 8 Kínai lapos	pw	Aug1d	Kína	1,33	36		Red June	ny	Jul2d	USA	2,17
12		Loadel	i	Aug1d	USA	0,50	37		Springcrest	py	Jul1d	USA	2,50
13		Manon	pw	Jul2d	USA	1,40	38		Independence	ny	Aug2d	USA	3,33
14		Maria Bianca	pw	Jul2d	ITA	0,67	39	Category 3	Weinberger	ny	Jul3d	ITA	4,00
15		Mariska	pw	Jul3d	HUN	0,70	40		Andosa	ny	Aug3d	USA	4,17
16		Meystar	pw	Aug2d	FRA	0,50	41		K 19	pw	Sept1d	Japán	4,40
17		Nectagrand	py	Jul2d	ITA	1,00	42		Rome Star	py	Aug2d	ITA	4,50
18		Nektár-H	pw	Aug2d	HUN	1,33	43		Rubinovüj	ny	Sept1d	UK	4,50
19		Nyikitszkij 85	ny	Aug2d	UK	0,70	44	Category 4	Rich Lady	py	Aug1d	USA	5,38
20		Orosz lapos	pw	Aug1d	UK	1,17	45		Summer Lady	py	Aug2d	USA	5,33
21		Pegaso	ny	Aug1d	ITA	1,80	46		Venus	ny	Aug3d	ITA	5,60
22		Red Rubin	ny	Jul1d	USA	1,63	47		Krümcsanyin	ny	Aug2d	UK	6,50
23		Redhaven	py	Aug1d	USA	1,00	48		Elberta	py	Aug3d	USA	7,00
24		Redhaven Bianca	pw	Jul3d	ITA	1,00	49		Flavortop	ny	Aug2d	USA	6,67
25		Shipley	pw	Sept2d	USA	1,00	50		Nectaross	ny	Aug2d	ITA	7,00

py-peach with yellow flesh, pw-peach with white flesh, pr-peach with red flesh, ny-nectarin with yellow flesh,
nw-nectarin with white flesh, i- industrial, d=decade

4.4. Fruit quality parameters of peach cultivars

Fruit quality parameters of peach cultivars in different degree of maturity were analysed based on two seasons, genotypes, cultivars, types of fruit and flesh colour of fruit. Physical and chemical parameters of peach cultivars were determined and compared to fruit weight, fruit size, cover colour, hue, firmness, soluble solid content and titratable acidity during ripening. Relationships among chemical parameters were also analysed. There were significant differences between the interaction of the cultivars and the seasons considering physical and chemical parameters as well ($p<0,001$). Differences among seasons could be explained by the amount of moisture. The year effect and cultivar effect also showed significant differences in both physical and chemical parameters ($p<0,05$). Differences among years are caused by different weathers. Peach cultivars were grouped into seven and five categories based on fruit weight, respectively in two seasons. The smallest fruits belonged to cultivars ‘Zsoltüj’ and ‘Adriana’ (99,73 g), the heaviest fruits belonged to cultivar ‘Michelini’. Peach fruits showed a smaller mean fruit weight in the year of 2015. Fruits of peach cultivars had significantly heavier fruit weight than nectarine cultivars in both years. However, nectarine cultivars had harder fruits and showed higher level of soluble solid content and titratable acidity than peach cultivars. White fleshed cultivars had also heavier fruit weight and harder flesh firmness compared to yellow flesh cultivars. Peach cultivars were grouped into six categories based on fruit diameter, ten and eight based on fruit height, and nine and seven based on thickness, respectively, every season. Nectarine cultivars showed smaller fruits compared to peach cultivars. ‘Incrocio Pieri’, ‘Padana’ és ‘Michelini’ showed the largest fruits among the cultivars. The largest cover colour appeared on cultivars ‘Olimpio’ and ‘Diamond Bright’. The deepest hue belonged to ‘Ambra’.

Cultivars showed a big variability comparing their chemical parameters. In the year 2014 cultivars showed lower amount of soluble solid content and flesh firmness and a higher amount of titratable acidity. The lowest amount of soluble solid content belonged to ‘Early Redhaven’ in both seasons. ‘Zsoltüj’ (year 2014) and ‘Incrocio Pieri’ (year 2015) showed the highest amount of soluble solid content. ‘Red Rubin’ had the softest flesh firmness in both years. ‘Olimpio’ (2014) and ‘August Red’ (2015) produced the hardest fruits. ‘Early Redhaven’ and ‘Red Rubin’ gave the fruits with lowest titratable acidity and ‘Adriana’ had the highest level of titratable acidity in both seasons.

There was a positive correlation between soluble solid content and the degree of maturity. Every cultivar showed different values of bivariete correlation (r). There was a negative correlation between soluble solid content and the flesh firmness. Every cultivar except ‘Padana’ showed different values of bivariete correlation. This characteristic is important for logistics. The strongest correlation belonged to cultivars ‘Zsoltüj’ and ‘Early Redhaven’.There was a negative correlation between soluble solid content and level of titratable acidity. Every cultivar showed different values of bivariete correlation (r). The strongest correlation (r) belonged to cultivars ‘Padana’ and ‘Ambra’.

5. NEW SCIENTIFIC RESULTS

1. Frost tolerance of flower buds of five peach cultivars was determined in dormant stage based on artificial freezing test, linear-regression and inverse models. Cultivars were grouped into three categories based on frost sensitivness.
2. Frost tolerance of two cultivars ‘Zsoltüj’ and ‘Rich Lady’ were determined.
3. Values between LT_{20} and LT_{80} of frost sensitive cultivars were determined by non-linear inverse model.
4. Susceptibility of fifty peach cultivars to leaf curl (*Taphrina deformans)* was determined and grouped into four categories.
5. Fruit quality parameters of peach cultivars ‘Adriana’, ‘Ambra’, ‘Diamond Bright’, ‘Zsoltüj’ were determined, in the climatic conditions of Hungary.
6. Relationship between soluble solid content of eight peach cultivars and their ripening stage, fleshfirmnes and titratable acidity, respectively, was determined based on Pearson correlation. Direction and strength of relationships were also determined.

6. DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1. Frost hardiness of peach cultivars

In preparation for the winter, the flower buds gradually develop frost resistance as a result of the joint effects of inherited genotypic traits and environmental factors(Minas et al. 2018a, Szabó et al. 2004) in addition, fruit growing technology also effects the frost tolerance (Dani et al. 2006). The flower buds of peaches are the most sensitive overwintering organs, that's why frost tolerance is supposed to be investigated based on flower buds (Szalay et al. 2010). Frost tolerance is characterizied with mean frost tolerance values (LT_{50}) which came from the results of researchers (Kaya et al. 2018, Minas et al. 2018a., Szalay et al. 2017).LT_{20}- and LT_{80}-values were determined for modeling the frost tolerance. Based on Gu's results (1999), values between LT_{20} and LT_{80} could be viewed as linear to count them. In our research frost sensitive peach cultivars could be modeled better with inverse-function. This result had not been published previously.

Based on our observations, peach cultivars reached their maximum LT_{50}during their endodormant period (December, January) in the investigated years. Our results matched other observations of frost tolerance in plum cultivars (Szalay et al. 2017), apricot cultivars (Szalay et al. 2016), peach cultivars (Minas et al. 2018a, Szalay et al. 2010) based on artificial freezing tests and field tests. Based on our results, the five peach cultivars measured by this thesis were grouped into three categories based on the avarages of their LT_{50}- values: (1) 'Rich Lady' (M=-16,200; SD=2,04) and 'Venus'(M=-17,141; SD=1,92) belonged to most frost sensitive category; (2) 'Redhaven'(M=-19,259; SD=1,73) belonged to category with moderate frost tolerance; (3) 'Piroska' (M=-21,253; SD=1,70) and 'Zsoltüj' (M=-21,741; SD=1,65) belonged to category with the highest frost tolerance. No previous results were found of LT_{50}-values of 'Zsoltüj' and 'Rich Lady' in the literature.

6.2. Susceptibility of peach cultivars to leaf curl *Taphrina deformans* /Berk./ tul.

Leaf curl caused by *Taphrina deformans*is one of the most dangoures fungi of peaches. That's why it is important to characterize the susceptibility of peach cultivars to leaf curl before growing them. Susceptibility of 250 peach cultivars to diseases were observed and evaluated by Ivascu and Buciumanu (2006) in Romania. Based on their observations, 10% of cultivars showed no or a little symptoms, 62% out of them were moderately susceptible and 28% out of them were very susceptible.

Our research concluded the same results as other observations. The most susceptible cultivars were characterized as having yellow flesh, whereas less susceptible cultivars tended to have white-fleshed fruit. Furthermore, nectarines were more susceptible than peaches (Mándoki 2009, Szlávik 2004). Cultivars originating from Central Asia showed different results compared to Timon's (1999a,b) observations, where no symptoms appeared at Szigetcsép. Observations of the 90s (Timon 1996) matched our researches mostly.

Based on a review from Soltész (1997), peach cultivars were grouped into three categories (weakly susceptible, moderately susceptible and highly susceptible). Based on his evaluation, cultivars in our category 1 belonged to weakly and moderately susceptible categories ('Harko', 'Suncrest', 'Mariska', 'Springtime'), whereas cultivars in our categories 2-

4 belonged to highly susceptible category. The trend based on susceptibility of the peach cultivars was the same compared to our observations. Cultivars with higher susceptibility also showed higher susceptibility in the review (’Springcrest’, ’Michelini’, ’Elberta’, ’Nectaross’, ’Venus’, ’Flavortop’, ’Andosa’).Klincsek (2001a,b,c,d, 2002, 2003a,b, 2004, 2005) and Szlávik (2004) evaulated the susceptibility of peach cultivars to leaf curl at Helvécia and Tordas, respectively. Based on their investigations, there could be five categories of susceptibility: no symptom, less susceptible, moderately susceptible, susceptible and highly susceptible. Our results mostly matched their observations. However cultivars ‘Suncrest’ and ‘Springtime’ were categorized by them into moderately susceptible group, whereas we took them into less susceptible categories (Category 1). Cultivar ’Independence’ was determined by us as moderately susceptible and cultivar ’Redhaven’ less susceptible at Soroksár.

Among other cultivars ‘Red June’, ‘Meystar’, ‘Manon’, ‘Redhaven’ and ‘Andosa’ were examined for ecological growing in Austria (Spornbereger at al. 2010). Cultivar ‘Andosa’ also was susceptible to leaf curl, whereas ‘Meystar’ and‘Manon’ showed less susceptibility. Sinkovits and Spornberger (1998) concluded that cultivar ‘Meystar’ could be grown in ecological technology or with reduced plant protection applied.

Predisposition of susceptibility to leaf curl could be effected by location, year and applied technology (Timon 1996, Horváth 2004a,b; Sinkovits és Sponberger 1998).Based on our research, it could be concluded, that peach cultivars without the adequate applied plant protection couldn’t be grown efficiently.

6.3. Fruit quality of peach cultivars

Market value of the fruits is determined primarily by their looks (Kader 1999, Crisosto és Crisosto 2005). Consumers' expectation is fruits with mid- or high weight in additionto expanded cover colour and depth hue (Szalay et al. 2017).

Growers used to forecast the yield based on weight (Cantín et al. 2010). Based on two-way ANOVA, the year effect impacts fruit weight and size. The year of 2015 was warmer than the year of 2014. Average amount of fruit weight have increased less due to less precipitation in the year of 2015. However, the average fruit size became larger rapidly due to the rains in the ripening period. Chaurasiya és Mishra (2017), Lopez et al. (2010) and other researchers (Bernát et al. 2008, Bonora et al. 2013) have concluded the same results in their works, that pruning, fruit thinning and irrigation effect the fruit size and fruit quality. Based on a review from Minas et al. (2018b), cooler weather causes larger fruits. This result matches our investigations. There was a quantity of precipitation in the year of 2014, which caused cooler weather during ripening season. Fruits have grown rapidly because of the absorbed moisture, however flesh firmness of the fruits has became softer due to the rapid growth. Cantín et al. (2010) breeded 15 new cultivars in mediterranean climate. Based on their evaulation, avarage fruit size of peaches is larger than nectarines, however peaches have less amount of cover colour, soluble solid content and titratable acidity compared to nectarines. Furthermore, nectarines are sweeter compared to peaches. Cultivars with yellow flesh have larger fruit size and less cover colour compared to white fleshed cultivars. Based on flesh colour of cultivars, the amount and ratio of chemical parameters are the same. Our observations match their evaulation in particular.

Alcobendas et al. (2013) have investigated the effects of irrigation and fruit position on size, colour, firmness and sugar contents of fruits in a mid-late maturing peach cultivar ‘Catherine’. Based on fruit diameter, fruits were grouped into six categories: AAA (80-90 mm), AA (73-80 mm), A (67-73 mm), B (60-67 mm), C (56-67 mm), D (<56 mm). Fruits belonged mostly to category AA. Based on the origin and types of cultivars, Reig et al. (2015) have examined 89 cultivars for two consecutive seasons. The avarege fruit size of the yellow fleshed nectarine ‘Diamond Bright’ was measured between 74,7 mm and 83,5 mm. Based on our measurments, the avarage fruit size of ‘Diamond Bright’ was smaller (between 53,88 and 59,28 mm).

Fruit weight of mid-June maturing cultivar ‘Adriana’ was measured between 50 and 119 g by Prenkic at al. (2016) from Montenegro, which measurment matches our observations (100-106 g). Bernát et al. (2008) in Hungary have investigated the effects of fruit thinning in a ecological peach orchard planted with cultivar ‘Suncrest’. Fruit thinning raised the fruit weight (105,39> 150,23 g) and fruit size (55 >65 mm) of ‘Suncrest’, however, its size parameters didn’t reach the size of white fleshed cultivar ‘Incrocio Pieri’ harvested at the same time.

Based on our evaulation, there were significant differences between years and cultivars considering cover colors. Nectarines and yellow fleshed cultivars showed more cover colours. Our results match Cantín et al. (2010) in particular. Based on a review from Crisosto (1994), light and fruit position on trees determine the amount of cover color. Adequate growing system is a need for the right cover colour and hue (Lal et al. 2017, Marini 2002). This could be the explanation that no significant differences were found considering colour hue, because samples were picked randomly from the parts of tree (shaded part, sunny part, top of the tree, bottom of the canopy). Based on our two investigated seasons, cultivar 'Zsoltüj' didn't have any cover colour. The deepest red hue belonged to cultivar 'Ambra' (8,75), whereas 'Early Redhaven' had the most pale hue (4,36). There are only a few literature considering colour hue (Maríni 2002).

Based on the examined cultivars, there are significant differences considering flesh firmness. Avarage flesh firmness of nectarines are higher than peaches. Our results didn't match earlier observations considering nectarines, which concluded that flash firmness of late-maturing cultivars have higher values than early-season cultivars (Montevicchi et al. 2012). E.g. flesh firmness of late-maturing 'Zsoltüj' is softer than mid-maturing cultivar 'Olimpio'. However, observations mentioned above are match our results considering peaches. It could be explained by micro climate conditions (Montevicchi et al. 2012).

Date of optimal harvest time depends on the types of markets and the storage-time. The well-mature grade (fruit firmness between 4,68 and 5,64 kg/cm^2) is used for fruit intended for one to two weeks storage and long distance markets, while the tree-ripe grade (fruit firmness between 3,12 and 3,74 kg/cm^2) is for fruit intended for less than one week storage and shipment to nearby or local markets (Minas et al. 2018b). Based ont he examined cultivars, the firmest fruit flesh belonged to 'Olimpio' in 2014 (6,18 kg/cm^2) and 'August Red' in 2015(10,65 kg/cm^2), respectively. The softest fruit firmness belonged to 'Red Rubin'(0,77 kg/cm^2) every seasons. Kader (1995) determined the minimum consumer acceptance in 10 Brix° and 27 N. Soluble solid content of cultivar 'Redhaven' on different rootstocks was between 8,7 and 10,6 Brix° in Slovenien (Orazem et al. 2013), cultivar 'Suncrest' located at an ecological peach orchard between

10 and 14 Brix° in Hungary (Bernát et al. 2008). Avarage soluble solid contents were in the same range in the world (Maulión et al. 2016, Forcada et al. 2014, Cascales et al. 2005, Orazem et al. 2013), however there are several differences among countries considering consumer acceptance. Based on the two investigated seasons, Brix°-values of the examined cultivars match Hungarian consumer acceptance and the minimum Brix°-values based on international literature.

The limit value between low-acid and high-acid fruit is 0,9% considering titratable acid content (Hilaire 2003, Abidi et al. 2011, Minas et al. 2018b). Cultivars 'Olimpio', 'August Red', 'Adriana' were higher than the limit value in the cooler season of 2014, whereas only 'Adriana' (1,2%) past the limit value in the warmer season of 2015.

Based on our results, it could be concluded, that there are a few cultivars only, which are suitable for Hungarian weather conditions considering stress tolerance, phenological characteristics and fruit quality parameters. Cultivar 'Zsoltüj' can be recommended to widen the range of cultivars because of its frost tolerance and looks. However its fruits are suitable for local market only, because of their short shelf-life. Furthermore 'Zsoltüj' could be a good breeding source because of its disease tolerance to leaf curl. Cultivar 'Adriana'could be recommended to fresh market because of its good chemical parameters, however further investigation of frost tolerance is needed considering its flower buds. Cultivar 'Ambra' is a nectarine which matures at the same period of the year as 'Early Redhaven'. It can be also recommended to widen the range of cultivars. Cultivar 'Vérbarack' (originally from Hungary) can be recommended to industrial processing, because of its biotic stress tolerance and high anthocyanin content also breeding sources. However location of planting must be chosen carefully because of its very late ripening season. Fruits of ‘Vérbarack’ aren’t showy, however they could be sold to fresh market with good marketing equipments. Cultivar ‘Rich Lady’ have the most showy fruits for fresh market among the investigated cultivars. However, frost tolerance of its flower buds is weak. That’s why, location of planting must be chosen carefully.

7. PUBLICATIONS RELATED TO THE SUBJECT OF THE PHD THESIS

Scientific articles in reviewed journals with impact factor (IF):

SZALAY L., **GYÖKÖS I.G**., BÉKEFI ZS. (2018): Cold hardiness of peach flowers at different phenological stages. *Horticultural Sciences Prague 45(3):*119–124. p. IF(2017): 0,500

Scientific articles in reviewed journals without impact factor (non-IF):

GYÖKÖS I.G., TIMON B., SZALAY L. (2015): Őszibarack- és nektarinfajták tafrinás betegségre való fogékonyságának értékelése. *Kertgazdaság47 (2):* 14-24. p.

SZALAY L.,**GYÖKÖS I. G.** (2016): Őszibarackfajták virágainak fagytűrő képessége. *Kertgazdaság 48 (3):* 34-40. p

Other scientific articles:

SZALAY L., **GYÖKÖS I. G**.- TIMON B. (2012): Őszibarackfajták téli fagykárosodása*Agrofórum 23 (5):* 94-95. p.

SZALAY L., DR. TIMON B., **GYÖKÖS I. G**. (2013): Az őszibarackfajtahasználatának változásai.*Agrofórum extra 48*. 22-26. p.

SZALAY L., **GYÖKÖS I. G**., TIMON B. (2014): UFO és társai – a lapos őszibarackok. *Agrofórum 25 (8):* 132-134. p.

Conference abstracts:

SZALAY L., **GYÖKÖS I. G**., HAJNAL V., TIMON B. (2015): Őszibarack fajtaérték-kutatás génbanki fajtagyűjteményben in XXI. Növénynemesítési Tudományos Napok. *MTA Agrártudományok Osztályának Növénynemesítési Tudományos Bizottsága Magyar Növénynemesítők Egyesülete*.36. p. ISBN: 978-963-8351-43-2

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