Doctoral (PhD) thesis

THE EFFECT OF ROOTSTOCK AND FLOWER THINNING ON THE FRUIT QUALITY OF SWEET CHERRY VARIETIES

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1. INTRODUCTION

Sweet cherry (*Prunus avium* L.) - because of its early ripening, attractive appearance and advantageous inner content values, is one of the most favored summer fruits both in Europe and in several other markets of the world. Yield of the sweet cherry is cca. 2000-2200 t/year worldwide, of which Europe's share is 30-40% (FAOSTAT 2015). During the history of its culture, several sweet cherry varieties were drawn into breeding and cultivation.

The sweet cherry varieties of today are well known to have different outer characteristics (fruit size, color, firmness) as well as different inner content values (sugar-, acid- and mineral content, vitamins, polyphenols, etc). However, more and more studies support that these characteristics do not depend only on the scion, but also the rootstock does influence certain quality parameters of the fruits, although the nature of this effect has not yet been clarified (AĞLAR és YILDIZ 2014, CANTÍN et al. 2010, GONÇALVES et al. 2005, GRATACÓS et al. 2008, JIMÉNEZ et al. 2004, LANAUSKAS et al. 2012, SIMON et al. 2004, SITAREK és BARTOSIEWICZ 2012, SPINARDI et al. 2005, SZOT és MELAND 2001, TAREEN és TAREEN 2006, USENIK et al. 2010).

In the last decade some articles indicated that flower thinning may also affect the quality parameters of sweet cherry fruit (AYALA és ANDRADE 2009, CITTADINI et al. 2013, SCHOEDL et al. 2009, WHITING és LANG 2004). However, there is no evident conclusion to be drawn from the contradictory results of the relatively small number of publications in this topic, and the question is still open, whether or not these effects exist, and if they do, in which way and to what degree they affect fruit quality.

Nowadays proper nutrition, and its health protective, illness-preventive effect, get more and more attention. The consumption of fresh fruits and vegetables with beneficial inner content values, as well as that of their products, is an essential part of it. For this reason, in order to satisfy consumer demands, sweet cherry producers have an interest in using grafts that produce fruits with the highest possible inner content value and health protective effect. In out reasearch, among others, we sought to find out which of the scion-rootstock combinations is the most fitting for this purpose, also, what positive influence flower thinning may have on the aforementioned characteristics.

2. RESEARCH AIMS

Aims of my research can be summarized in the following points:

1)

a) Mapping and characterizing the fruit quality of 'Kordia' and 'Regina' scions grafted on GiSelA 5’, ‘GiSelA 6’, ‘PHL-C’, ‘PiKu 1’ and ‘Weiroot 158’ rootstocks, via measurement of various physical, chemical and constitutional properties (fruit size, fruit and stone mass, firmness, color, detachment force of fruit stalk, total water-soluble solids, as well as profile of individual carbohydrates, acids and polyphenols), through years of different weather conditions.

b) Monitoring fruit quality in the course of ripening process

c) Getting answer, via statistical analysis of the collected data, to the question of whether the rootstock has any influence on fruit quality of the scion, and if it does, in what way, and to what extent.

d) Making recommendations, based on the results, for scion-rootstock combinations that are optimal for a given purpose.

2)

a) Mapping and characterizing the fruit quality flower-thinned and control trees of Bigarreau Burlat Schreiber’, ‘Bigarreau Burlat VG’, ‘Bigarreau Moreau’, ‘Hybrid 222’ and ‘Merton Premier’ scions grafted on GiSelA 5’ rootstocks, via measurement of the above mentioned properties, through years of different weather conditions.

b) Monitoring fruit quality in the course of ripening process

c) Getting answer, via statistical analysis of the collected data, to the question of whether the flower thinning has any influence on fruit quality of the various scions, and if it does, in what way, and to what extent.

d) Making recommendations, based on the results and in alignment with any given production target, for applicability of flower thinning with regards to the studied scion-rootstock combinations.

3. MATERIAL AND METHOD

3.1. Location of the field investigations

Sweet cherry fruits were sampled in Austria, in the experimental plantation of BOKU (Universität für Bodenkultur Wien) Department of Applied Plant Sciences (Department für Nutzpflanzenwissenschaften) Institute of Horticulture and Viticulture (Abteilung für Obst- und Weinbau), located in the North-northeastern part of Vienna, in Jedlersdorf district.

3.2. Soil and climate

The soil- and climatic conditions of the Jedlesdort experimental plantation, located in the Vienna Basin, match those of the sweet cherry production territories in Hungary. In the area there is thick layered chernozem soil with intermediate humus content (BFW 2015). Top layers of the soil are calcic and alkaline. Erosion is not significant. Texture of the soil is loam, with high water retention capacity (220-300 mm/100cm).

Altitude of the exparimental plantation is 162m. Climate is characterized by subcontinental climatic effect, warm and dry summer, and moderately cold winter. The average annual temperature is 9,8°C, sunlit hours add up to an average of 1800 hours/year. Average amout of precipitation is 500-600mm/year, the biggest portion falling during the summer months (BOKU 2015, ZAMG 2015).

3.3. The range of varieties involved in the study

During the study of rootstock effect (Plantation Q10), the effect of 5 different rootstocks (‘GiSelA 5’, ‘GiSelA 6’, ‘PHL-C’, ‘PiKu 1’ and ‘Weiroot 158’) on 2 scions (‘Regina’ és ‘Kordia’) were examined, with regards to quantitative and qualitative parameters of the fruit. During the bloom thinning experiments (Plantation Q26), fruits of 5 different scions (‘Bigarreau Burlat Schreiber’, ‘Bigarreau Burlat VG’, ‘Bigarreau Moreau Schreiber’, ‘Merton Premier’ és ‘Hybrid 222’) grafted on the same rootstock (‘GiSelA 5’) were compared on thinned and control trees.

3.4. Sampling method

During our studies fruits of Plantation Q10 were collected in 4 consecutive years (2010-2013), fruits of Plantation Q26 in 3 consecutiv years (2010-2012), in three states of ripening: in the beginning of coloration (T1), in the second half of coloration (T2) and in fully ripened state (T3).

3.5. Studied quantitative and qualitative parameters of the sweet cherry fruit

Testing the physical and physicochemical parameters of the cherry fruit was carried out in the Fruit and Vegetables Analytical Laboratory of BOKU (A-1190 Wien, Peter-Jordan-Straße 82), immediately after the sampling.

Studied physical parameters were the following: 3 types of fruit diameter (width, depth, heigth), fruit volume (calculated value), fruit- and stone mass, useful fruit ratio (calculated value), firmness, color, detachment force of fruit stalk. Studied physico-chemical parameters were: total water-soluble solids (TSS) and titratable acids (TA)

Individual components and component groups were determined with High Performance Liquid Chromatography technique, in the HPLC laboratory of Department of Pomology, Faculty of Horticultural Science, Corvinus University of Budapest, using a Waters HPLC istrument (Waters Corporation, 34 Maple Street, Milford, MA 01757, USA). The analyzed individual sugar compounds were the following: glucose, fructose, sorbitol. The analyzed individual acid compounds were: malic acid, succinic acid, citric acid. The analyzed individual polyphenolic compounds were: cyanidin-3-O-rutinoside, quercetin, quercetin-3-rutinoside, chlorogenic acid, neochlorogenic acid, catechin, and 3-p-coumaroylquinic acid.

3.6. Statistical evaluation

Statistical data analysis was conducted using IBM SPSS Statistics 22.0.0.0 software. The parameters were first classified into coherent groups, then the dependent variables were analyzed by MANOVA models four factors. The multivariable outliers were eliminated by Chi-square test, using Mahalanobis distances (Filzmoser et al. 2008). In case MANOVA results revealed significant effects, factor effects were tested by follow-up one-way ANOVA models. Normailty of error terms was accepted based on Shapiro-Wilk's test or, in case it was significant, on skewness and kurtosis (Tabachnick és Fidell 2013, D’Agostino et al. 1990). Homogeneity of variances was checked by Levene's test. If homogeneity criteria was met then Tukey's, otherwise Games-Howell's post-hoc test was carried out.

4. RESULTS AND CONCLUSIONS

4.1. Comparative evaluation of fruit physical properties

4.1.1. Fruit sizes, fruit volume

Size is one of the most tangible properties of sweet cherry fruit. Its significance in the consumer acceptance of the fruit depends on the cultural background, so, for example, according to a Japanese survey, size has little weight in buyer's decisions (DEVER et al. 1996), while in European type cultures (e.g. Europe, USA), in most cases, size parameter is of primary importance for consumers (TURNER et al. 2008).

4.1.1.1. Plantation Q10

Investigating the rootstock effect we could, in accordance with literature data, identify a significant difference regarding the size of fruits (AĞLAR és YILDIZ 2014, GADŽE et al. 2010, SZOT és MELAND 2001). If performances of the rootstocks are compared with each other, in case of 'Kordia', it is shown that fruits of ‘GiSelA 6’ exceeded the average size of the five rootstocks significantly in two years, while fruits of ‘GiSelA 5’, ‘PHL-C’ and ‘Weiroot 158’ did the same in one year each. Fruits of ‘PiKu-1’ had never outgrown the average. Based on our data, the best chance of reaching the highest fruit sizes on ‘Kordia’ scion is when combined with ‘GiSelA 6’ rootstock, and from this point of view ‘PiKu-1’ rootstock is the least recommendable.

Analyzing the data of ‘Regina’ scion with the same method it was found that highest chance of getting bigger sized fruits lies with ‘GiSelA6’, ‘PHL-C’ and ‘Weiroot 158’ rootstocks, and view ‘PiKu-1’ is the least recommendable.

4.1.1.2. Plantation Q26

With regards to the effect of flower thinning it was found that in all those cases, when there was a significant difference between flower-thinned and control trees (61.36% of all cases), fruits of the treated trees were bigger, without exception. During the 3 years, in T3 phase, averagely 46.7% of the varieties reacted to the flower thinning with bigger fruits. It is likely that year effect also influences the effect of flower thinning, because in in 2012 the number of positive reactions increased by 37% compared to the previous years. It is also well apparent that among the scions only ‘BMS’ reacted consistently, in each year, positively to flower thinning, ‘MP’ did it twice, the other varieties only once out of three years.

4.1.2. Fruit and stone mass, useful fruit ratio

4.1.2.1. Plantation Q10

Analysis of fruit masses yielded trends that were analogous to those of fruit volumes. Examining the rootstock effect we could demonstrate, in accordance with the literature, a significant difference in terms of fruit masses (CANTÍN et al. 2010, GADŽE et al. 2010, GRATACÓS et al. 2008, GYEVIKI et al. 2008, LANAUSKAS et al. 2012, SIMON et al. 2004, SITAREK és GRZYB 2010, VERCAMMEN and VANRYKEL 2014). Comparing the rootstocks in case of 'Kordia' scion, 'GiSelA 6' continued to be the best choice of rootstock for bigger fruit mass, while 'PiKu 1' the least recommendable. However, according to our tests, the measurement uncertainty of fruit mass is much lower than that of the size parameters.

Due to the comparatively smaller relative standard deviations, the value order, with regards ot fruit mass, of the three recommendable rootsocks can now be deermined: 1. 'PHL-C', 2. 'Weiroot 158', 3. 'GiSelA 6'

About stone masses it can be stated that average stone masses ot the 'Kordia' scion is very much independent of the year effect, especially compared to 'Regina', in the data of which the year effect is powerfully evident. There are significant differences between the rootstocks in the combinations of both scions, but in our opinion the practical impact of these differences is negligible.

In the literature, for demonstrating the relationship of fruit flesh and stone, usually the fruit/stone ratio is employed (AĞLAR and YILDIZ 2014, KALYONCU et al. 2009, MRATINIĆ et al. 2011, SZOT and MELAND 2001, VURSAVUŞ et al. 2006). In our opinion, a more expressive quantity is the useful fruit ratio, given in percentage of the full fruit mass. In average of the 4 years, 'Kordia' showed the best useful fruit ratio on 'PHL-C' rootstock, while 'GiSelA 5' is the least recommendable. Among the combinations of 'Regina', similarly, one of the best is 'PHL-C', the other is 'GiSelA 6', while the weakest performance was showed by 'GiSelA 5' and 'PiKu 1'. The average difference, over 4 years, between the best and the worst combinations ('Kordia'-'PHL-C' and 'Regina'-'PiKu 1', respectively) was 1.58%

4.1.2.2. Plantation Q26

The general picture derived from the fruit mass data of Plantation Q26 is, as expected, very much similar to that obtained from fruit volumes.

Based on our results it can be concluded that trends of stone masses alone do not carry too much information. That much can be stated that, similarly to fruit sizes, flower thinning does not alway causes significant effect, but when it does, it always causes higher stone masses, without exception. However, in this case bigger is not better, because fruit stones are basically useless from further utilization's point of view. ‘BBS’ and ‘BMS’ varieties, similarly to previous cases, show above average values, the others move together in 3 year's average.

We determined that in the case of ‘BBVG’, ‘BMS’ and ‘H222’ varieties, in 3 years average, the useful fruit ratio improved with flower thinning by 0.3-0.5%, while the sensitivity to year effect decreased by 16.5-64.3%. The ‘BBS’ was insensitive to flower thinning from useful mass point of view, while ‘MP’ behaved the same way from year effect point of view.

4.1.3. Fruit skin color

Color is, next to the size, the other obvious external characteristic of the sweet cherry fruit, and has similarly a primary impact on consumer acceptance. According to the research of CRISOSTO et al. (2003), buyer's decisions are influenced, beside the sugar content, mainly by color: based on his results buyers find the deep dark, bordeaux colored, nearly black cherries the most attractive.

4.1.3.1. Plantation Q10

The effect of rootstocks on development of color, within any given year is almost always significant, at both scions. CANTÍN et al. (2010), GADŽE et al. (2010) and GONÇALVES et al. (2005) also found significant differences between the rootstocks.

The best recommended rootstock for ‘Kordia’, the one which most frequently and most intensively induced dark fruit skin color, was the ‘PHL-C’. For those, however, who would rather favor lighter, vividly red colored cherries, ‘GiSelA 6’ rootstock can be recommended. In case of ‘Regina’ variety, dark color of the fruits is best facilitated by ‘PiKu 1’, while for lighter fruits ‘GiSelA 5’ and ‘GiSelA 6’ can be recommended.

4.1.3.2. Plantation Q26

Based on our research it can be stated that with regards to color of ‘BBS, ‘BBVG’ and ‘H222’ varieties flower thinning produces darker fruits, and in the case of ‘BBS’ this is enhanced with less sensitivity to year effect. Fruits of ‘BMS’ and ‘MP’ will be lighter as an effect of flower thinning, with vivid red color. In 3 years average the darkest fruits were grown on ‘BMS’ among the control trees, and on ‘BBVG’ among the treated ones. Of the two the control ‘BMS’ fruit was darker.

4.1.4. Fruit firmness

It is a generally valid statement that greater fruit firmness, within the practical limits, is always better. It improves the transportability of the fruit (SAN MARTINO et al. 2008), and consumer demands are best met by higher firmness values (KAPPEL et al. 1996, GARCIA-MONTIEL et al. 2010).

4.1.4.1. Plantation Q10

Studying the rootstock effect we could show significant differences with regards to fruit firmness, in accordance with literature data (CANTÍN et al. 2010, GONÇALVES et al. 2005, JIMÉNEZ et al. 2004, SZOT and MELAND 2001, USENIK et al. 2010). In case of Regina it can be stated that for better fruit firmness 'GiSelA 5' and 'GiSelA 6' are the best recommendable rootstocks. If only favorable years are regarded, 'GiSelA 6' gave a bit better averages, however, it was very susceptible to year effect, and the 2^{nd} worst average firmness value of the whole 4 years was also linked to this rootstock. On the other hand, 'GiSelA 5' generally showed a little bit lower average values throughout the years, but its fluctuation caused by year effect was less, so its 4 years average firmness (3.51 kg/cm^2) is better that that of 'GiSelA 6' (3.45 kg/cm^2). The averagely softest fruits were found with 'PHL-C' rootstock.

Based on 4 years performance, the circle of recommendable rootstocks for 'Kordia' could be narrowed down to 3. The firmest fruits were grown on 'GiSelA 5', 'PHL-C' and 'GiSelA 6', but in the time frame of the experiment we could not observe any trends that would effectively make a significant difference between them. The softest fruits were produced on 'Weiroot 158' roostock.

4.1.4.2. Plantation Q26

Regarding fruit firmness of Plantation Q26, the same can be said as with fruit sizes, namely that when flower thinning has a significant effect on firmness (in 42.22% of all cases), then it is always (100%) positive. From this follows that - strictly from firmness point of view - no harm can come out of executing the treatment.

Although it was stated that flower thinning brings positive results for all varieties, perhaps also the extent the effect is not irrelevant. In 3 years average, the treatment caused a 17.9% increase of firmness for 'MP' fruits, 12.4% for 'BBS' fruits, and between 3.6%-7.2% for the rest.

4.2. Comparative evaluation of general physicochemical parameters

4.2.1. Total water-soluble solids contetnt (TSS), titratable acid content (TA), TSS-TA relationship

In consumer acceptance, a factor of primary importance is the flavour of the sweet cherry (TURNER et al. 2008, GARCIA-MONTIEL et al. 2010, DEVER et al. 1996), which depends basically on the harmonic, ballanced combination of sugar and acid content of the fruit. According to REVELL (2008) this is realized when the fruit has both high sugar and hich acid content, the measure of which are the TSS and TA numbers, respectively (GIRARD és KOPP 1998, TURNER et al. 2008, VURSAVUȘ et al. 2006).

4.2.1.1. Plantation Q10

Regarding the rootstock effect on TSS and TA, so far we have only found contradicting results in the literature. According to SZOT and MELAND (2001), JIMÉNEZ et al. (2004), SIMON et al. (2004), GRATACÓS et al. (2008), CANTÍN et al. (2010) and SITAREK and GRYZB (2010), TSS value of the fruits is affected by rootstock component of the graft but, on the other hand, LANAUSKAS et al. (2012), SITAREK and BARTOSIEWICZ (2012) and AĞLAR and YILDIZ (2014) could not find significant difference between the effect of the rootstocks. In relation of TA values of the fruits, SZOT and MELAND (2001), GRATACÓS et al. (2008) and CANTÍN et al. (2010) successfully demonstrated the rootstock effect, while JIMÉNEZ et al. (2004), SIMON et al. (2004) and GONÇALVES et al. (2005) could not find significant difference between the effect of the rootstocks. Our results, in both cases, are in favor of the rootstock effect, meaning that we could show significant differences between the TSS and TA values of fruits of trees standing on different rootstocks.

When evaluating the rootstocks, effects on the development of TSS and TA must be appraised in a complex way. It is most favored when a rootstock exerts positive influence on both parameters, and it is least favored when it shows negative correlation with both of them. Based on this principle, among the 'Kordia' combinations the best rating was given to 'GiSelA 5', which in 2 out of 4 years had improved both parameters, and in the other 2 years it had no considerable effect. The weakest performance was given by 'GiSelA 6', which had usually lowered both TSS and TA compared to the average. Among the 'Regina' combinations, based on the same principle, the best evaluation was given to 'Weiroot 158', which performed above average in both parameters, while the least recommendable was 'GiSelA 5', where the acid content was below average in each year.

It should be noted, however, that if evaluation was done based on the TSS/TA ratio, disputed by us but supported by many others, completely different outcome would be reached. The TSS content of fruits of 'Regina' on 'GiSelA 5' rootstock was in all 4 years average ot little above average, while the TA value was always significantly below the average. But for this latter reason alone, TSS/TA ratio of 'GiSelA 5' was always outstanding, and based on the traditional evaluation it would have got the best rating. Yet we gave it the worst one.

4.2.1.2. Plantation Q26

Following the previous logic, it is generally concluded that flower thinning exerts (or not) a different influence on the verieties. In case of 'BBVG' the fruit's flavor quality is improved, in case of 'BMS' it is deteriorated by the treatment, while in case of the other varieties the effect depends very much on the year, so no conclusion ov broad validity can be made.

4.3. Comparative evaluation of individual components and component groups

4.3.1. Sugar fractions

In earlier chapters it had already been mentioned that higher sugar content improves the market value of sweet cherry fruit, and positively influences buyer's decisions, especially in case of returning buyers. Beyond this, knowledge of concentration values of certain sugar compounds is of paramount importance especially in case of certain - existing or developing - illnesses, such as, for example, type 2 diabetes mellitus (FICZEK 2012, FORD és MOKDAD 2001, STANHOPE et al. 2009, TAPPY 2012).

4.3.1.1. Plantation Q10

Chromatographic analysis of individual sugar components covered in our case three carbohydrates, out of which glucose and fructose were dominant by terms of concentration, next to them sorbitol played only a smaller role. Sorbitol's ratio to total chromatographic sugar content (TCS) was between 12-18%, fructose was between 33-39%, and glucose between 45-55%. Our results are in agreement with the literature: according to JIMÉNEZ et al. (2004), sorbitol in the fruits of 'Sunburst' variety is between 16.1-18.1%, while fructose and glucose between 37.13-37.63% and 44.76-46.27%, respectively, depending on rootstock, in proportion of TCS. The results of USENIK et al. (2008) were a little bit different: sorbitol, fructose and glucose was found between 3.91-11.37%, 41.81-43.21% and 45.42-54.28%, respectively, in comparison of 8 sweet different cherry varieties.

In the concentrations of glucose and fructose a strongly parallel tendency can be discovered: whenever in the fruit of a certain scion-rootstock combination (in T3 state of ripening) the glucose content is high, fructose is also high, and when glucose is low, fructose is also low.

Studying the rootstock effect we concluded that in 4 years average it was the rootstock 'PiKu 1' that exerted the most advantageous influence on both scions, resulting in the significantly highest sugar levels. In the case of 'Kordia' we could determine that from TCS point of view 'Weiroot 158' is the least recommendable rootstock. For 'Regina' there was no significant difference between the four lower performing rootstocks.

4.3.1.2. Plantation Q26

The effect of flower thinning is evidently present in the case of 'BBVG' and 'H222' varieties, as the TCS content of the fruits, in 3 years average, leaped to 172.2 mg/ml and 177.8 mg/ml, respectively, in correlation with the treatment. The other varieties did not show significant differences. In the case of 'BBVG', 'H222' and 'MP' varieties, as a consequence of the flower thinning, the relative standard deviation of the yearly averages did significantly increase, which shows that the treatment significantly augments the sensitivity to year effect. In the case of 'BMS' the standard deviation decreased considerably, by 'BBS' it effectively did not change.

With regards to individual sugar components it can be said that in the fruit of each tree (treated and control ones alike) the ratio of fructose in proportion to the TCS was 42 ± 1%, glucose was 49 ± 1%, and sorbitol was 9 ± 2%. We concluded that there is no difference between the cultivars from sugar ratios point of view, so neither variety is more advantageous or risky than the others for consumers sensitive to sugar composition.

4.3.2. Acid fractions

As mentioned earlier, beside the sugars, acid content is the other most important factor affecting the fruit flavour. On the other hand, equally important is for the food industry the deepest possible knowledge of the feedstock's composition. Distribution of the acid components can affect, among others, the corrosion paths (as well as corrosion control) of processing industry machineries, the amount of additives (e.g. citric acid) used to secure the reliably constant quality of the product, in accordance with consumer demands, and also the treatment possibilities of the industrial waste water and other side products created during the food processing (STABNIKOVA et al. 2005).

4.3.2.1. Plantation Q10

Chromatographic analysis of individual acid components covered in our case 3 componds: malic, succinic and citric acids. In the acid distribution there are similar trends that we have found at the sugars: development of the acid components is very much alike, concentrations the three acids changed more or less together. Malic acid was dominant in all scion-rootstock-year combinations, its ratio relative to total chromatographic acids (TCA) was between 59-76%, while succinic acid had 14-28% and citric acid had 10-14%. Observations of SERRADILLA et al. (2011) are in consent with our results: in their tests of Ambrunés' sweet cherry they found 65.74-66.27% for malic acid, 21.62-22.46% for succinic acid, and 11.79-12.11% for citric acid.

Comparing the rootstocks, the excellent performance of 'GiSelA 6' and 'PiKu 1' is worthy of note.The highest malic, succinic and citric acid concentrations of the fruits was measured in 45.83% of all cases on 'GiSelA 6', and in 33.34% on 'PiKu 1' rootstocks. The other three rootstocks shared the remaining 20.83%. To increase the acid content of 'Kordia', in case of all three acid components, the first choice of recommendation is 'GiSelA 6' rootstock, albeit 'GiSelA 5' also showed relatively high values. In case of 'Regina' variety 'PiKu 1' is the most recommended, and we awarded the 2nd place to 'GiSelA 6'.

4.3.2.2. Plantation Q26

Comparing the chromatographic acid content (TCA) we concluded that the picture is not quite as uniform as in the case of glucose-fructose-sorbitol. The control trees of the five cultivars can be divided into 3 categories, based on the 3 years average TCA value. The lowest TCA values were shown by ‘BBS’ and ‘MP’ (5.35-5.40 mg/ml), the middle level was populated by ‘BMS’, while the highest values were produced by ‘H222’ and ‘BBVG’ cultivars (7.12-7.33 mg/ml).

Due to flower thinning, in 3 years average, the TCA value of all varieties were reduced by 6-10%, except with ‘BBVG’, where the TCA did not change. The rankings of the cultivars were not changed. With regards to disrtibution of the acids one of the scions differed significantly from the rest: in the fruits of ‘MP’ malic acid was responsible for 77%, succinic acid for 13% of the TCAm in 3 years average. In case of the other scions, malic acid was between 68-71%, succinic acid was between 18-19%. This observation can be interesting from food processing point of view. Citric acid was in all varieties between 11-15%. Flower thinning had no influence on the acid distribution with any of the cultivars.

4.3.3. Polyphenol fractions

The polyphenol content of the sweet cherry fruit has several important, positive healthcare implications. Polyphenols have a very wide range of chemical and biological activity, most of the compounds can probably prevent or confine the development of several illnesses (DUTHIE et al. 2000, FERRETTI et al. 2010, HARDCASTLE et al. 2011, HUANG and FERRARO 1992, JACOB et al. 2003, KANDASWAMI AND MIDDLETON 1994, KUPPUSAMY et al. 1990, LUGASI 2000, RONG 2010, YAO et al. 2004). In broad generality it can be said that the higher is the polyphenol concentration in fresh fruits or vegetables, the higher is their beneficial effect on health.

According to TREUTTER (2006) it is also worth mentioning the fact that synthesis of polyphenols is part of the self defense strategy of the plants. VILLARINO et al. (2011), for example, demonstrated that the high chlorogenic acid and neochlorogenic acid content of unripe peach fruit improves the resistance of the fruit against *Monilinia laxa* pathogen. Mechanism of the effect is based on the chlorogenic acids' blocking the synthesis of melatonin in the hyphas, thus it is likely that these conclusions are valid also for the sweet cherry, because the effect of chlorogenic acids is not fungi-specific.

4.3.3.1. Plantation Q10

According to our measurements, the total chromatographic polyphenol content (TCPP) was dominated by two components: neochlorogenic acid and cyanidin-3-rutinoside (further on referred to as cyanidin), since the concentration of these two exceeded the others by sometimes two or three orders of magnitude. The concentration of the two main polyphenol component changes in the opposite direction during the ripening process: the neochlorigenic acid decreases, the cyanidin monotonously increases, and it is their balance that basically determines the development of TCPP.

Our conclusions are supported by literature data (JAKOBEK et al. 2009, MOZETIČ et al. 2004, KELEBEK és SELLI 2011, SERRADILLA et al. 2011).

In comparison of the rootstocks, analyzing the TCPP data measured in T3 state of ripening, we determined that - among the combinations of 'Kordia' scion - highest levels of TCPP in ripened fruits are expected on 'GiSelA 5' rootstock, and besides 'Weiroot 158' is also recommendable. In the case of 'Regina' cultivar the 'PHL-C' rootstock proved to be the best, although between 'PHL-C' and the next two best rootstocks ('PiKu 1' and 'GiSelA 5') there is no statistically significant difference.

If, separately, only the cyanidin content is examined in context of the 'Kordia' scion, the most preferential values are shown by 'Weiroot 158' and 'GiSelA 5', in this order. In the case of 'Regina' cultivar 'PHL-C' and 'PiKu 1' rootstocks are recommendable.

In contrast to cyanidin, in studying the chlorogenic acids, primarily the T1 state of ripening is interesting, because according to VILLARINO et al. (2011) this is the most important period with regards to the plant's self defense mechanism. Examined separately the T1 term we found that in 66.7% of all cases the total amount of chlorogenic acids was most favorable on 'GiSelA 6' rootstock.

All in all, the most advantageous polyphenol content in sweet cherry fruits, in case of 'Kordia' scion is promised by 'GiSelA 5' and 'GiSelA 6' rootstocks, while for 'Regina' cultivar the rootstocks 'PiKu 1' and 'PHL-C' are the most recommended.

4.3.3.2. Plantation Q26

From the aspect of the concentration of the most important polyphenols, and also the TCPP value, 'BBS' and 'BBVG' varieties usually reacted positively to flower thinning treatment, 'BMS' usually negatively, while for the other rootstocks there was no evident correlation.

4.4. Summary

During the 4 years of our research we have collected and and analyzed more than 55,000 data in order to determine how the quality parameters of sweet cherry fruit are influenced by - among others - the rootstock or the flower thinning treatment. We sought correlations, regularities, tendencies, by which we might rank the rootstocks and the technology (i.e. flower-thinned vs. control tree).

Looking at the results on the whole, one of the most important conclusion is that it is impossible to predict the quality parameters of the fruits from one single year's data. The year effect - that includess several known and unknown, not controllable factors - has a high influence on the behavior of fruit trees, which might result in tendencies valid and solid in one year turning to their opposites in the next year. Such a great volatility of fruit parameters makes stability and predictability all the more valuable, and the ability remain unaffected by environmental effects becomes one of the most important traits of fruit trees. This ability is expected to become especially valuable in the future because, as a result of the global climatic change, years of very different weather will follow each other, which will make a definite difference in crop quality and yield (CHMIELEWSKI et al. 2004, MENZEL et al. 2006).

The other important conclusion is that there is no such thing as "best rootstock", "best scion" or "best technology". Even if resutls are viewed within one year, it often happens that one advantageous feature of the fruit is best enhanced by one rootstock, the other by the other, and then one needs to contemplate which feature is more valuable. This contemplation can only be done if the purpose of usage is known (ROMANO et al. 2006, KADER 1999).

As a synthesis - or essence - of our results, conclusions and suggestions we have prepared an evaluation matrix (or summary table) with regards to the effect of rootstocks and flower thinnig, which can be used by growers, with knowledge of the purpose of usage, to select the optimal scion-rootstock combination (Table 2) or optimal technology (i.e flower thinnig vs control) (Table 1) in order to reach the desired fruit quality.

Table 1: Evaluation matrix about the effect of flower thinning on qualitative and quantitative parameters of the fruits of 5 different sweet cherry cultivars

Attribute	Scion	Flower thinning improves	Flower thinning indifferent
Bigger fruit size	BBS	X	
	BBVG	X	
	BMS	X	
	H222	X	
	MP	X	
Bigger fruit mass	BBS	X	
	BBVG	X	
	BMS	X	
	H222	X	
	MP	X	
Greater firmness	BBS	X	
	BBVG	X	
	BMS	X	
	H222	X	
	MP	X	
Brighter, more vividly red fruits	BBS		X
	BBVG		X
	BMS	X	
	H222		X
	MP	X	

Attribute	Scion	Flower thinning improves	Flower thinning indifferent	Flower thinning reduces
Harmonic, good flavor (TSS-TA relationship)	BBS		X	
	BBVG	X		
	BMS			X
	H222		X	
	MP		X	
Higher total chromatographic sugar content	BBS		X	
	BBVG	X		
	BMS			X
	H222	X		
	MP			X
Higher total chromatographic acid content	BBS			X
	BBVG	X		
	BMS			X
	H222		X	
	MP		X	
Higher total chromatographic polyphenol content	BBS	X		
	BBVG	X		
	BMS			X
	H222		X	
	MP		X	

Table 2: Evaluation matrix about the effect of 5 different rootstocks on qualitative and quantitative parameters of the fruits of 'Regina' and 'Kordia' scions

Attributes - 'Kordia'	Rootstock affects positively	Average rootstock effect	Rootstock affects negatively
Bigger fruit size	GiSelA 6	GiSelA 5 PHL-C Weiroot 158	PiKu 1
Bigger fruit mass	GiSelA 6	GiSelA 5 PHL-C Weiroot 158	PiKu 1
Higher useful fruit ratio	PHL-C	GiSelA 6 PiKu 1 Weiroot 158	GiSelA 5
Higher stalk detachment force	PHL-C Weiroot 158	GiSelA 5 GiSelA 6	PiKu 1
Darker fruits	PHL-C	GiSelA 5 PiKu 1 Weiroot 158	GiSelA 6
Greater firmness	GiSelA 5 GiSelA 6 PHL-C	PiKu 1	Weiroot 158
Harmonic, good flavor (TSS-TA relationship)	GiSelA 5	PHL-C PiKu 1 Weiroot 158	GiSelA 6
Higher total chromatographic sugar content	PiKu 1	GiSelA 5 GiSelA 6 PHL-C	Weiroot 158
Higher total chromatographic acid content	GiSelA 6	GiSelA 5	PHL-C PiKu 1 Weiroot 158
Higher chloronenic and neochlorogenic acid content in T1 state of ripening	GiSelA 6	GiSelA 5	PHL-C PiKu 1 Weiroot 158
Higher cyanidin concentration	Weiroot 158	GiSelA 5 PHL-C	GiSelA 6 PiKu 1
Higher total chromatographic polyphenol content	GiSelA 5 Weiroot 158	PHL-C	GiSelA 6 PiKu 1

Attributes - 'Regina'	Rootstock affects positively	Average rootstock effect	Rootstock affects negatively
Bigger fruit size	GiSelA 6 PHL-C Weiroot 158	GiSelA 5	PiKu 1
Bigger fruit mass	PHL-C Weiroot 158	GiSelA 6	GiSelA 5 PiKu 1
Higher useful fruit ratio	PHL-C GiSelA 6	Weiroot 158	GiSelA 5 PiKu 1
Higher stalk detachment force	Weiroot 158	GiSelA 5 GiSelA 6 PiKu 1	PHL-C
Darker fruits	PiKu 1	PHL-C Weiroot 158	GiSelA 5 GiSelA 6
Greater firmness	GiSelA 5 GiSelA 6	PiKu 1 Weiroot 158	PHL-C
Harmonic, good flavor (TSS-TA relationship)	Weiroot 158	GiSelA 6 PHL-C PiKu 1	GiSelA 5
Higher total chromatographic sugar content	PiKu 1	GiSelA 6 PHL-C Weiroot 158	GiSelA 5
Higher total chromatographic acid content	PiKu 1	GiSelA 6	GiSelA 5 PHL-C Weiroot 158
Higher chloronenic and neochlorogenic acid content in T1 state of ripening	GiSelA 6	GiSelA 5 PHL-C	PiKu 1 Weiroot 158
Higher cyanidin concentration	PHL-C PiKu 1	Weiroot 158	GiSelA 5 GiSelA 6
Higher total chromatographic polyphenol content	PiKu 1 PHL-C	GiSelA 5	GiSelA 6 Weiroot 158

5. NEW SCIENTIFIC ACHIEVEMENTS

The new scientific achievements of my PhD research are the following:

1. **Unprecedented comprehensive analysis of ‘Merton Premier’ and ‘Hybrid 222’ sweet cherry cultivars grafted on ‘GiSelA 5’ rootstock, and their evaluation basaed on physical parameters and inner content values that determine market value.**

Parameters that were measured, analyzed and evaluated:

- fruit size, fruit volume, fruit and stone mass, useful fruit ratio, fruit firmness, stalk detachment force, fruit color
- total water-soluble solids content, total titratable acid content
- individual sugar (fructose, glucose, sorbitol), acid (malic, succinic, citric) and polypehol (cyanidin-3-O-rutinoside, quercetin, quercetin-3-rutinoside, chlorogenic acid, neochlorogenic acid, catechin, and 3-p-coumaroylquinic acid) fractions

2. **Unprecedented comprehensive comparison and evaluation of five early ripening sweet cherry cultivars with regards to the effect of flower thinning on fruit quality, and furthermore, confirmation of this effect on the five involved varieties.**

Confirmation of the effect of flower thinning:

- confirmation of positive effect, with regards to fruit size, fruit mass and firmness, for all five varieties
- confirmation of brighter, more vividly red skin color of the fruits in the case of ‘BMS’ and ‘MP’ cultivars
- confirmation of positive effect in the case of ‘BBVG’, and negative effect in the case of ‘BMS’ cultivars, on flavor quality (TSS-TA relationship) of the fruits
- regarding the concentrations of individual sugar components, confirmation of positive effect in the case of ‘BBVG’ and ‘H222’
- from individual acid components point of view, confirmation of negative effect in the case of ‘BBS and ‘BMS’, and positive effect in the case of ‘BBVG’ cultivars
- from total chromatographic poliphenols point of view, confirmation of positive effect in the case of ‘BBS and ‘BBVG’, and negative effect in the case of ‘BMS’ cultivars

3. **Unprecedented comprehensive comparison and evaluation of all combinations of two late ripening sweet cherry scions and five rootsocks with regards to the effect of rootstock on fruit quality, and furthermore, confirmation of this effect on the involved scion-rootstock combinations.**

Confirmation of the rootstock effect:

- confirmation of positive effect on fruit size and fruit mass in the case of ‘Kordia’ scion on ‘GiSelA 6’ rootstock, in the case of ‘Regina’ scion on ‘PHL-C’ and ‘Weiroot 158’ rootstocks, and confirmation of negative effect in the case of both varieties on ‘PiKu 1’ rootstock.
- regarding fruit firmness, confirmation of positive effect in the case of both cultivars on ‘GiSelA 5’ and ‘GiSelA 6’ rootstocks, confirmation of negative effect with ‘Kordia’ scion on ‘Weiroot 158’ rootstock, and with ‘Regina’ scion on ‘PHLC’ rootstock
- confirmation of brighter, more vividly re skin color of fruits in the case of ‘Kordia’ variety on ‘GiSelA 6’ rootstock, ‘Regina’ variety on ‘GiSelA 5’ and ‘GiSelA 6’ rootstocks, while also confirming darker skin color with ‘Kordia’ on ‘PHLC’ rootstock, and ‘Regina’ on ‘PiKu 1’ rootstock.
- regarding fruit flavor quality (TSS-TA relationship), confirmation of positive effect in the case of ‘Kordia’ scion on ‘GiSelA 5’, ‘Regina’ scion on ‘Weiroot 158’ rootstock, confirmation of negative effect with ‘Kordia’ scion on ‘GiSelA 6’ rootstock, and with ‘Regina’ scion on ‘GiSelA 5’ rootstock
- regarding the concentration of individual sugar components, confirmation of positive effect in the case of both scions on ‘PiKu 1’ rootstock, confirmation of negative effect with ‘Kordia’ scion on ‘Weiroot 158’ rootstock, and with ‘Regina’ scion on ‘GiSelA 5’ rootstock
- regarding the concentration of individual acid components, confirmation of positive effect in the case of ‘Kordia’ variety on ‘GiSelA 6’ rootstock, and in the case of ‘Regina’ variety on ‘PiKu 1’ rootstock
- regarding the total chromatographic polyphenol content, as well as concentrations of individual polyphenol components, confirmation of positive effect in the case of ‘Kordia’ variety on ‘GiSelA 5’, ‘GiSelA 6’ and ‘Weiroot 158’ rootstocks, and in the case of ‘Regina’ variety on ‘PiKu 1’ and ‘PHLC’ rootstocks

4. Unprecedented comprehensive analysis and comparative evaluation of the individual polyphenol fractions, indicating the health protective value, of the fruits of fifteen sweet cherry scion-rootstock combinations

Analyzed and evaluated individual polyphenol fractions:

- cyanidin-3-O-rutinoside, quercetin, quercetin-3-rutinoside, chlorogenic acid, neochlorogenic acid, catechin, and 3-p-coumaroylquinic acid

5. Demonstration of the year effect within the effect of rootstocks and treatment (flower thinning) on fruit quality of sweet cherry

Confirmation of the year effect's interference:

- with the effect of ‘GiSelA 5’, ‘GiSelA 6’, ‘PHLC’, ‘PiKu 1’, ‘Weiroot 158’ rootstocks, in the case of ‘Regina’ and ‘Kordia’ scions, with regards to the following parameters: fruit size, fruit mass, stalk detachment force, fruit skin color, fruit firmness, total soluble solids content, total titratable acids content, concentrations of individual sugar, acid and polyphenol components
- with the effect of flower thinning, in the case of ‘Bigarreau Burlat Schreiber’, ‘Bigarreau Burlat VG’, ‘Bigarreau Moreau Schreiber’, ‘Hybrid 222’, ‘Merton Premier’ cultivars grafted on ‘GiSelA 5’ rootstock, with regards to the following parameters: fruit size, fruit mass, stalk detachment force, fruit skin color, fruit firmness, total soluble solids content, total titratable acids content, concentrations of individual sugar, acid and polyphenol components

6. Unprecedented research into the field of fruit quality, the results of which - due to the fact that the soil and climatic conditions of the location of sampling are very much similar to those of the Hungarian ones - are well adaptable in the domestic sweet cherry growing sectors.

Results that are well adaptable:

- Results pertaining to the analysis of fruit quality of 15 scion-rootstock combinations
- Results confirming the effect of rootstock in case of 10 scion-rootstock combinations
- Results confirming the effect of flower tinning in the case of 5 scions (‘Bigarreau Burlat Schreiber’, ‘Bigarreau Burlat VG’, ‘Bigarreau Moreau Schreiber’, ‘Hybrid 222’, ‘Merton Premier’) grafted on ’GiSelA 5’ rootstock

7. Unprecedented confirmation of the fact that the withing-the-component-group-ratios of the sugar, acid and polyphenol components are unchanged by the effects of rootstock, flower thinning and year in the case of the 15 scion-rootstock graft combinations involved in the research.

8. Development and application of a novel, two dimensional method, replacing the widely used TSS/TA ratio, for a better demonstration and evaluation of the flavor quality of fruits, that can give practical help to growers and users in defining and monitoring the desired fruit quality.

9. Development of an evaluation matrix for a circle of the studied sweet cherry scions and rootstocks, which can give practical help in selecting the optimal scion-rootstock combination or technology (i.e. flower thinning) in order to reach the desired fruit quality.

Literature

1. AĞLAR E. és YILDIZ K. (2014): Influence of rootstocks (Gisela 5, Gisela 6, MaxMa, SL 64) on performance of '0900 Ziraat' sweet cherry. *Journal of Basic & Applied Sciences*, 10:60-66., ISSN: 1927-5129, DOI: http://dx.doi.org/10.6000/1927-5129.2014.10.09
2. AYALA M. és ANDRADE M.P. (2009): Effects of fruiting spur thinning on fruit quality and vegetative growth of sweet cherry (*Prunus avium*). *Cien. Inv. Agr.* 36 (3):443-450. DOI: http://dx.doi.org/10.4067/s0718-16202009000300011
3. BFW (2015): Digitale Bodenkarte. Bundesforschungs- und Ausbildungszentrum für Wald, Naturgefahren und Landschaft. http://bfw.ac.at/rz/bfwcms.web?dok=7066 (2015.09.29)
4. BOKU (ANONYM) (2015): Versuchszentrum Jedlersdorf, Obstbau und Gartenbau. https://www.dnw.boku.ac.at/gb/organisation/versuchszentrum-jedlersdorf/ (2015.09.27)
5. CANTÍN C. M., PINOCHET J., GOGORCENA Y., MORENO M. A. (2010): Growth, yield and fruit quality of 'Van' and 'Stark Hardy Giant' sweet cherry cultivars as influenced by grafting on different rootstocks. *Scientia Horticulturae*, 123 (3):329-335. DOI: 10.1016/j.scienta.2009.09.016
6. CHMIELEWSKI F. M., MÜLLER A., BRUNS E. (2004): Climate changes and trends in phenology of fruit trees and field crops in Germany, 1961–2000. *Agricultural and Forest Meteorology*, 121 (1):69-78. doi:10.1016/S0168-1923(03)00161-8
7. CITTADINI E. D., BALUL Y. J., ROMANO G. S., PUGH A. B. (2013): Effect of intensity and time of thinning on yield and fruit quality of cherry cultivation. *RIA, Revista de Investigaciones Agropecuarias*, 39 (1):51-59. ISSN0325-8718, URL: http://ria.inta.gov.ar/wp-content/uploads/2013/04/RIA39-1abril20133.pdf
8. CRISOSTO C. H., CRISOSTO G. M., METHENEY P. (2003): Consumer acceptance of 'Brooks' and 'Bing' cherries is mainly dependent on fruit SSC and visual skin color. *Postharvest Biology and Technology*, 28 (1):159-167., doi:10.1016/S0925-5214(02)00173-4.
9. D'AGOSTINO R. B., BELANGER A., D'AGOSTINO R. B. JR. (1990): A suggestion for using powerful and informative tests of normality. *The American Statistician*, 44 (4):316–321. JSTOR 2684359., DOI: 10.1080/00031305.1990.10475751
10. DEVER M. C., MACDONALD R. A., CLIFF M. A., LANE W. D. (1996): Sensory evaluation of sweet cherry cultivars. *HortScience*, 31 (1):150-153.
11. DUTHIE G. G., DUTHIE S. J., KYLE J. A. M. (2000): Plant polyphenols in cancer and heart disease: implications as nutritional antioxidants. *Nutr. Res. Rev.*, 13:79-106. doi: 10.1079/095442200108729016.
12. FERRETTI G., BACCHETTI T., BELLEGGIA A., NERI D. (2010): Cherry Antioxidants: From Farm to Table. *Molecules*, 15:6993-7005; DOI:10.3390/molecules15106993
13. FICZEK G. (2012): Hazai alma- és meggyfajták humán egészségvédő és felhasználhatósági értékei gyümölcsanalízis alapján (Doktori értekezés, Budapesti Corvinus Egyetem)
14. FILZMOSER P., MARONNA R., WERNER M. (2008): Outlier identification in high dimensions, *Computational Statistics and Data Analysis*, 52 (3):1694-1711., doi:10.1016/j.csda.2007.05.018
15. FORD E. S., & MOKDAD A. H. (2001): Fruit and vegetable consumption and diabetes mellitus incidence among US adults. *Preventive medicine*, 32(1):33-39.
16. GADŽE J., PELAIĆ I., RADUNIĆ M., ČMELIK Z. (2010): Pomological characteristics and fruit colour of sweet cherry cultivar Lapins grafted on different vegetative rootstocks. *Pomologia Croatica*, 16 (1-2):37-42.
17. GARCIA-MONTIEL F., SERRANO M., MARTINEZ-ROMERO D., ALBURQUERQUE N. (2010): Factors influencing fruit set and quality in different sweet cherry cultivars. *Spanish Journal of Agricultural Research*, 8 (4):1118-1128. DOI: 10.5424/sjar/2010084-1238
18. GIRARD B. és KOPP T. G., (1998): Physicochemical Characteristics of Selected Sweet Cherry Cultivars. *J. Agric. Food Chem.*, 46:471−476. DOI: http://dx.doi.org/10.1021/jf970646j
19. GONÇALVES B., MOUTINHO-PEREIRA J., SANTOS A., SILVA A. P., BACELAR E., CORREIA C., ROSA E. (2005): Scion–rootstock interaction affects the physiology and fruit quality of sweet cherry. *Tree Physiology*. 26:93-104. DOI: 10.1093/treephys/26.1.93
20. GRATACÓS E., CORTÉS A., KULCZEWSKI B. M. (2008): Rootstock effects on two sweet cherry cultivars in central chile. *Acta Horticulturae* 795:227-238. URL: http://www.actahort.org/books/795/795_31.htm
21. GYEVIKI M., BUJDOSÓ G., HROTKÓ K. (2008): Results of cherry rootstock evaluations in Hungary. *International Journal of Horticultural Science*, 14 (4)11-14.
22. HARDCASTLE A. C., AUCOTT L., REID D. M., MACDONALD H. M. (2011): Associations Between Dietary Flavonoid Intakes and Bone Health in a Scottish Population, *Journal of Bone and Mineral Research*, 26 (5):941–947; DOI: 10.1002/jbmr.285

23. HUANG M. T. és FERRARO T. (1992): Phenolic compounds in food and cancer prevention. In Phenolic compounds in food and their effects on health II. Szerk.: Huang, M. T., Ho, C., Lee. C. Y. New York, *ACS Symposium Series*, 507:8-34.
24. JACOB R. A., SPINOZZI G. M., SIMON V. A., KELLEY D. S., PRIOR R. L., HESS-PIERCE B., KADER A. A. (2003): Consumption of Cherries Lowers Plasma Urate in Healthy Women. *J. Nutr*., 133:1826-1829, http://www.ncbi.nlm.nih.gov/pubmed/12771324
25. JAKOBEK L., ŠERUGA M., VOĆA S., ŠINDRAK Z., DOBRIČEVIĆ N. (2009): Flavonol and phenolic acid composition of sweet cherries (cv. Lapins) produced on six different vegetative rootstocks. *Scientia Horticulturae*, 123:23–28., DOI: 10.1016/j.scienta.2009.07.012
26. JIMÉNEZ S., GARÍN A., ALBÁS E. S., BETRÁN J. A., GOGORCENA Y., MORENO M. A. (2004): Effect of several rootstocks on fruit quality of 'Sunburst' sweet cherry. *Acta Horticulturae* 658:353-358., URL: http://www.actahort.org/books/658/658_51.htm
27. KADER A. A. (1999): Fruit maturity, ripening, and quality relationships. In International Symposium Effect of Pre-& Postharvest factors in Fruit Storage, *Acta Hort. (ISHS)*, 485:203-208.
28. KALYONCU I. H., ERSOY N., YILMAZ M. (2009): Some physico-chemical properties and mineral contents of sweet cherry (*Prunus avium* L.) type grown in Konya. *African Journal of Biotechnology*, 8 (12):2744-2749.
29. KANDASWAMI C. és MIDDLETON E. JR. (1994): Free radical scavenging and antioxidant activity of plant flavonoids. *Adv. Exp. Med. Biol.*, 366:351-376.
30. KAPPEL F., FISHER-FLEMING B., HOGUE E. (1996): Fruit characteristics and sensory attributes of an ideal sweet cherry. *HortScience*, 31 (3):443-446.
31. KELEBEK H. és SELLI S. (2011): Evaluation of chemical constituents and antioxidant activity of sweet cherry *(Prunus avium L.*) cultivars. *International Journal of Food Science and Technology*, 46:2530–2537; DOI: 10.1111/j.1365-2621.2011.02777.x
32. KUPPUSAMY U. R., KHOO H. E., DAS N. P. (1990): Structure-activity studies of flavonoids as inhibitors of hyaluronidase. *Biochem. Pharm.*, 40:397-401.
33. LANAUSKAS J., USELIS N., KVIKLYS D., KVIKLIENĖ N., BUSKIENĖ L. (2012): Rootstock effect on the performance of sweet cherry cv. Lapins. *Hort. Sci. (Prague)*, 39:55–60.
34. LUGASI A. (2000): Az élelmiszereredetű flavonoidok potenciális egészségvédő hatása. *Orvosi Hetilap*, 141(32): 1751-1760.
35. MENZEL A., SPARKS T. H., ESTRELLA N., KOCH E., AASA A., AHAS R., ... & ZUST A.N.A. (2006): European phenological response to climate change matches the warming pattern. *Global Change Biology*, 12 (10):1969-1976.
36. MOZETIČ B., TREBŠE P., SIMČIČ M., HRIBAR J. (2004): Changes of anthocyanins and hydroxycinnamic acids affecting the skin colour during maturation of sweet cherries (*Prunus avium* L.). *LWT-Food Science and Technology*, 37 (1):123-128. doi:10.1016/S0023-6438(03)00143-9
37. MRATINIĆ E., POPOVSKI B., MILOŠEVIĆ T., POPOVSKA M. (2011): Postharvest chemical, sensorial and physical-mechanical properties of wild apricot (*Prunus armeniaca* L.). *Notulae Scientia Biologicae*, 3 (4):105-112.
38. REVELL J. (2008): Sensory profile and consumer acceptability of sweet cherries. Thesis submitted to the University of Nottingham for the degree of Masters of Research
39. ROMANO G. S., CITTADINI E. D., PUGH, B., SCHOUTEN R. (2006): Sweet cherry quality in the horticultural production chain. *Stewart Postharvest Review*, 2 (6):1-9.
40. RONG T. (2010): Chemistry and Biochemistry of Dietary Polyphenols, Nutrients, 2:1231-1246; DOI:10.3390/nu2121231
41. SAN MARTINO L., MANAVELLA F. A., GARCÍA D. A., SALATO G. (2008): Phenology and fruit quality of nine sweet cherry cultivars in South Patagonia. In V International Cherry Symposium, *Acta Hort. (ISHS)*, 795:841-848.
42. SCHOEDL K., DENK A., HUMMELBRUNNER S., MODL P., FORNECK A. (2009): No improvement in fruit quality through chemical flower thinning in sweet cherry (*Prunus avium L.*). *J. Sci. Food Agric.*, 89:1236–1240., doi: 10.1002/jsfa.3581
43. SERRADILLA M. J., LOZANO M., BERNALTE M. J., AYUSO M. C., LÓPEZ-CORRALES M., GONZÁLEZ-GÓMEZ D. (2011): Physicochemical and bioactive properties evolution during ripening of 'Ambrunés' sweet cherry cultivar. *LWT-Food Science and Technology*, 44 (1):199-205., doi:10.1016/j.lwt.2010.05.036

44. SIMON G., HROTKÓ K., MAGYAR L. (2004): Fruit quality of sweet cherry cultivars grafted on four different rootstocks. *Acta Horticulturae,* 658:365-370., URL: http://www.actahort.org/books/658/658_53.htm
45. SITAREK M. és BARTOSIEWICZ B. (2012): Influence of Five Clonal Rootstocks on the Growth, Productivity and Fruit Quality of 'Sylvia' and 'Karina' Sweet Cherry Trees. *Journal of Fruit and Ornamental Plant Research*., 20 (2):5–10, ISSN (Print) 1231-0948, DOI: 10.2478/v10290-012-0010-z
46. SITAREK M. és GRZYB Z. S. (2010): Growth, productivity and fruit quality of 'Kordia'sweet cherry trees on eight clonal rootstocks. *Journal of Fruit and Ornamental Plant Research*, 18 (2):169-176.
47. SPINARDI A. M., VISAI C., BERTAZZA G. (2005): Effect of rootstock on fruit quality of two sweet cherry cultivars. *Acta Horticulturae*, 667:201-206. URL: http://www.actahort.org/books/667/667_29.htm
48. STABNIKOVA O., WANG J. Y., DING H. B. (2005): Biotransformation of vegetable and fruit processing wastes into yeast biomass enriched with selenium. *Bioresource Technology*, 96 (6):747-751.
49. STANHOPE K. L., SCHWARZ J. M., KEIM N. L., GRIFFEN S. C., BREMER A. A., GRAHAM J. L., HAVEL, P. J. (2009): Consuming fructose-sweetened, not glucose-sweetened, beverages increases visceral adiposity and lipids and decreases insulin sensitivity in overweight/obese humans. *The Journal of Clinical Investigation*, 119 (5):1322.
50. SZOT I. és MELAND M. (2001): Influence of rootstocks on size distribution and fruit quality of sweet cherry cultivars. *International Agrophysics*, 15 (3):207-214.
51. TABACHNICK B. G. és FIDELL L. S. (2013): Using Multivariate Statistics, 6th ed., Boston, Pearson
52. TAPPY L. (2012): Q&A: 'Toxic' effects of sugar: should we be afraid of fructose?. *BMC Biology*, 10 (1):42.
53. TAREEN M. J., és TAREEN M. N. (2006): Effect of rootstocks on II. Rainier cherry grown in Balochistan (Pakistan). *International Journal of Agriculture and Biology*, 8 (1):55-56.
54. TREUTTER D. (2006): Significance of flavonoids in plant resistance: a review. *Environmental Chemistry Letters*, 4 (3):147-157. DOI 10.1007/s10311-006-0068-8
55. TURNER J., SEAVERT C., COLONNA A., LONG L. E. (2008): Consumer sensory evaluation of sweet cherry cultivars in Oregon, USA. In V International Cherry Symposium, *Acta Hort. (ISHS)*, 795:781-786.
56. USENIK V., FAJT N., MIKULIC-PETKOVSEK M., SLATNAR A., STAMPAR F., VEBERIC R. (2010): Sweet cherry pomological and biochemical characteristics influenced by rootstock. *Journal of Agricultural Food Chemistry*, 58 (8):4928–4933., DOI: 10.1021/jf903755b
57. VERCAMMEN J. és VANRYKEL T. (2014): Use of Gisela 5 for sweet cherries. In VI International Cherry Symposium, *Acta Hort. (ISHS*), 1020:395-400.
58. VILLARINO M., SANDÍN-ESPAÑA P., MELGAREJO P., DE CAL A. (2011): High chlorogenic and neochlorogenic acid levels in immature peaches reduce *Monilinia laxa* infection by interfering with fungal melanin biosynthesis. *Journal of Agricultural and Food Chemistry*, 59 (7):3205-3213.
59. VURSAVUŞ K., KELEBEK H., SELLI S. (2006): A study on some chemical and physico-mechanic properties of three sweet cherry varieties (*Prunus avium* L.) in Turkey. *Journal of Food Engineering*, 74 (4):568-575.
60. WHITING M. D. és LANG G. A. (2004): 'Bing' sweet cherry on the dwarfing rootstock 'Gisela 5': Thinning affects fruit quality and vegetative growth but not net CO2 exchange. *Journal of the American Society for Horticultural Science*, 129 (3):407-415.
61. YAO L. H., JIANG Y. M., SHI J., TOMAS-BARBERAN F. A., DATTA N., SINGANUSONG R., CHEN S. S. (2004): Flavonoids in food and their health benefits. *Plant Foods for Human Nutrition*, 59:113–122. DOI: 10.1007/s11130-004-0049-7
62. ZAMG (ANONYM) (2015): Klimadaten Österreich 1971-2000, Klimastation Gr. Enzersdorf. http://www.zamg.ac.at/fix/klima/oe71-00/klima2000/klimadaten_oesterreich_1971_frame1.htm (2015.09.27)

Publications related to the subject of the PhD thesis

Scientific articles in reviewed journals with impact factor (IF)

1. SPORNBERGER A., **HAJAGOS A**., MODL P., VEGVARI GY. (2015): Einfluss der Unterlage auf Wuchs, Ertrag und Fruchtqualität von Süßkirschen (*Prunus avium* L.) der Sorten Regina und Kordia im Nachbau in Ostösterreich. Erwerbs-Obstbau, 57:(2) pp. 63-69. IF: 0,25 (2014)
2. SPORNBERGER A., BUVAC D., **HAJAGOS A.**, LEDER L., BÖCK K., KEPPEL H., VEGVARI G. (2014): Impact of a mechanical flower thinning on growth, yield, diseases and fruit quality of sweet cherries (*Prunus avium* L.) under organic growing conditions. Biological Agriculture & Horticulture, 30:(1) pp. 24-31. IF: 0,681 (2014)
3. **HAJAGOS A.** & VÉGVÁRI Gy. (2013): Investigation of tissue structure and xylem anatomy of eight rootstocks of sweet cherry (*Prunus avium* L.). Trees, Vol. 27 (1): pp. 53-60. IF: 1,869 (2013)
4. SIMON G., **HAJAGOS A**., GHASEMI S. & VÉGVÁRI Gy. (2012): Fruit quality analysis of two new promising Hungarian sweet cherry (*Prunus avium* L.) cultivars on different rootstocks. Acta Alimentaria, Vol. 41: pp. 180-186. IF: 0,475 (2012)

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

1. VÉGVÁRI G., HROTKÓ K., MAGYAR L., **HAJAGOS A.**, CSIGAI K. (2008): Histological investigation on cherry rootstocks. Acta Horticulturae 795: 339-344.

Conference proceeding full paper

1. **HAJAGOS A.**, SPORNBERGER A., MODL P., VÉGVÁRI GY. (2012): The effect of rootstocks on the development of fruit quality parameters of some sweet cherry (*Prunus avium* L.) cultivars 'Regina' and 'Kordia', during the ripening process. Acta Universitatis Sapientiae, Agriculture and Environment, 4: 59−70.
2. SPORNBERGER A., BUVAC D., LEDER L., BÖCK K., OSTOJIC S., TELFSER J., **HAJAGOS A.**, VEGVARY G., KEPPEL H., MODL P. (2012): The impact of flower and fruit thinning methods on yield, diseases and fruit quality of sweet cherries (*Prunus avium*) under organic growing conditions In: Foerdergemeinschaft Oekologischer Obstbau e.V. (Ed.), Proceedings of the 15th International Conference on Organic Fruit-Growing, p. 209-214.
3. **HAJAGOS A.**, SPORNBERGER A., MODL P., TÓTH M., VÉGVÁRI Gy. (2011): Alanyválasztás és piacképesség kapcsolata a cseresznyetermesztésben. LIII. Georgikon Napok, 53rd Georgikon Scientific Conference, Keszthely, p. 335-345.

Conference proceeding abstract

1. **HAJAGOS A.**, MODL, P., SPORNBERGER, A., VÉGVÁRI, GY. (2012): Study of inner values of several cherry (*Prunus avium* L.) varieties In the Abstracts of 47th Croatian and 7th International Symposium on Agriculture, Section 9. Pomology, Opatija, p. 253.
2. **HAJAGOS A.**, SPORNBERGER A., MODL P., VÉGVÁRI Gy. (2011): The effect of rootstocks on development of fruit quality parameters of some sweet cherry (*Prunus avium* L.) cultivars, 'Regina' and 'Kordia', during the ripening process. 1. Transilvanian Horticulture and Landscape Studies Conference, Abstracts, Tirgu-Mures, Marosvásárhely. p. 31.

Citations in international journals

HAJAGOS A. & VÉGVÁRI Gy. (2013): Investigation of tissue structure and xylem anatomy of eight rootstocks of sweet cherry (*Prunus avium* L.). Trees, Vol. 27 (1): pp. 53-60. **IF: 1,869** (2013)
- citated:

1. CHEN B., WANG C., TIAN Y., CHU Q., HU C. (2015): Anatomical characteristics of young stems and mature leaves of dwarf pear. Scientia Horticulturae (ISSN: 0304-4238) 186: pp. 172-179.
2. DONG X., CAO Y., WANG K., TIAN L., ZHANG Y., QI D. (2015): Comparison of the Characters and Distribution of Vessel Elements in Xylem Among Three Main Pear Rootstocks in China. Chinese Bulletin of Botany (ISSN: 1674-3466) 50: (2) pp. 227-233.
3. LJUBOJEVIĆ M., OGNJANOVA V., ZORIĆ L., MAKSIMOVIĆ I., MERKULOV L., BOŠNJAKOVIĆ D., BARAĆ G. (2013): Modeling of water movement trough cherry plant as preselecting tool for prediction of tree vigor. Scientia Horticulturae (ISSN: 0304-4238) 190: pp. 189-197.
4. JIMÉNEZ S., DRIDI J., GUTIÉRREZ D., MORET D., IRIGOYEN J. J., MORENO M. A., GOGORCENA Y. (2013): Physiological, biochemical and molecular responses in four *Prunus* rootstocks submitted to drought stress. Tree Physiology (ISSN: 0829-318X) 33: (10) pp. 1061-1075.

VÉGVÁRI G., HROTKÓ K., MAGYAR L., **HAJAGOS A.**, CSIGAI K. (2008): Histological investigation on cherry rootstocks. Acta Horticulturae 795: 339-344.
- citated:

1. BARYŁA P., KAPŁAN M., KRAWIEC M. (2014): The effect of different types of rootstock on the quality of maiden trees of sweet cherry (*Prunus avium* L.) cv.'Regina'. Acta Agrobotanica (ISSN: 0065-0951) 67: (4) pp. 43-50.
2. STACHOWIAK A., ŚWIERCZYŃSKI S., KOLASIŃSKI M. (2014): Growth and yielding of aweet cherry trees grafted on new biotypes of *Prunus* (L.). Acta Scientiarum Polonorum – Hortorum Cultus (ISSN: 1644-0692) 13: (5) pp. 131-143.

3. Baryła P., Kapłan M., Krawiec M., Kiczorowski P. (2013): The effect of rootstocks on efficiency of a nursery of sweet cherry (*Prunus avium* L.) trees cv. 'Regina'. Acta Agrobotanica (ISSN: 0065-0951) 66: (4) pp. 121-128.
4. Ljubojević M., Ognjanov V., Zorić L., Maksimović I., Merkulov L., Bošnjaković D., Barać G. (2013): Modeling of water movement trough cherry plant as preselecting tool for prediction of tree vigor. Scientia Horticulturea (ISSN: 0304-4238) 160: pp. 189-197.
5. Zorić L, Ljubojević M, Merkulov, Luković J, Ognjanov V. (2012): Anatomical Characteristics of Cherry Rootstocks as Possible Preselecting Tools for Prediction of Tree Vigor. Journal of Plat Growth Regulation (ISSN: 0721-7595) 31: (3) pp. 320-331.
6. Ljubojević M., Ognjanov V., Bošnjaković D., Barać G., Mladenović E., Čukanović J. (2011): Sortiment trešnje za intenzivne zasade. Zbornik Naucnih Auchnih Radova Instituta PKB Agroekonomik (ISSN: 0354-1320) 17: (5) pp. 5-11.
7. Ljubojević M., Ognjanov V., Čukanović J., Mladenović E. (2011): Selekcija slabobujnih podloga za višnju is trešnju. In: Proceedings of the 3rd Conference „Innovation in fruit Growing". Belgrad: Universitet u Beogradu Poljoprivredni fakultet, (ISBN 978-86-7834-116-8) pp. 205-215.

Themeleader and participant of international and scientific R&D projects

1. Stiftung Aktion Österreich-Ungarn/Osztrák-Magyar Tudományos és Oktatási Akció Alapítvány – Title of the project: „Der Einfluss von verschiedenen Sorten-Unterlagen-Kombinationen auf die Fruchtqualität und auf die Inhaltsstoffe der Süsskirsche (*Prunus avium* L.) in den österreichischen und ungarischen Anbauregionen" – contract number: 82öu15 - 268/2011