

PhD thesis

**ANALYSIS OF ANTIOXIDANT CAPACITY OF STONE FRUITS
AND POLYPHENOLIC COMPOSITION OF SOUR CHERRIES**

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INTRODUCTION AND AIMS

The geographical attributes of Hungary foster fruit cultivation. Beside these attributes the technological conditions and the genetic parameters of cultivars involved in cultivation are also important factors. In the 21st century, owing to the growing expectations of the consumers, growers and the food industry face novel challenges. Today a fresh fruit should be aesthetic, should lack any damage, and should have a long shelf-life, meanwhile, in the case of a fruit-based product the positive health effects are also of concern. That is the reason of the current functional breeding programs, which aim the production of genotypes with improved health effect and the subsequent processing of such fruits into functional food.

The term ‘functional food’ was used first in Japan in 1991 [VERES *et al.*, 2003]. In Europe, after the funding of *Functional Food Science in Europe* (FUFOSE) EU organization, requirements of functional food were set. A food-stuff that, beside its normal nutritional value, positively affects some function of human body (such as improving its defense mechanism, preventing diseases like hyperthonia or hyperglycemia) could be called functional food.

As a part of healthy way of living fruit containing foods are more and more important. It is a proven fact that the consumption of adequate quantity of fruit and vegetable prevents diseases, but still, we do not consume enough. The favorable health effects of fruits are caused by additive and synergistic effects of the almost 8000 fitochemicals found in them. These compounds can help preventing some civilizational diseases [BLOCK *et al.*, 1992; LAW and MORRIS, 1998], furthermore, overdosing these compounds is not of concerns owing to the fact that they are consumed in their natural form. A solution for the inadequate fruit consumption could be the production of foodstuffs beloved by consumers. Products that consumers prefer over a fresh apple or some cherries, and which are available during the whole year.

Beside apple the most cultivated fruits (approx. 34%) are stone fruits (**Fig. 1**). Among stone fruits the most important is cherry (12% of total fruits cultivated), followed by peach (8%), plum (7%) and apricot (5%) [KSH, 2011]. It is worth mentioning, that while the total yield of these fruits is lower than that of apple, the average price of such fruits are much higher.

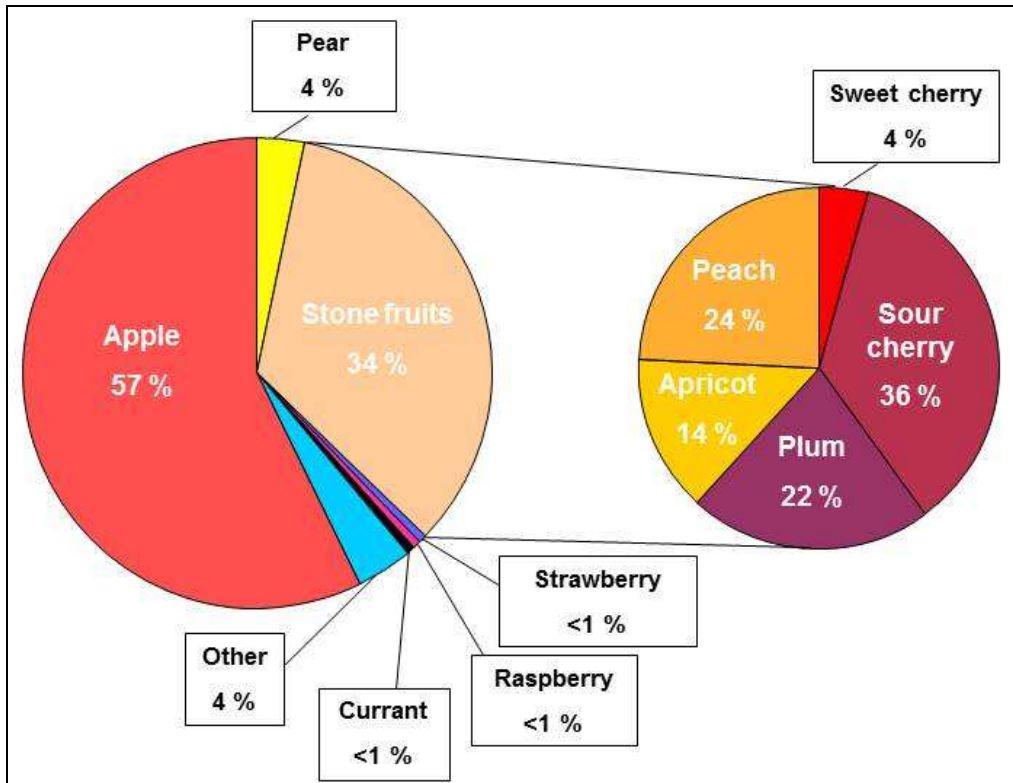


Fig.1. Percentage distribution of fruit production in Hungary in 2011 [KSH, 2011].

The Carpatian basin is the secondary gene-centre of cherry [HROTKÓ, 2003]. It spread in Hungary in the 17th century and it is a popular fruit ever since. Its popularity is well represented by the numerous village names containing the word ‘meggy’ which means tart cherry (Fig. 2).



Fig. 2. Hungarian villages containing the word ‘meggy’ (meaning sour cherry) in their name.

A very rich cultivar assortment is available for the growers. From this assortment the cultivar is chosen according to specific requirements (e.g. high economic yield). The processing industry has not recognized yet the characteristic differences among specific cultivars. It may help selling more of their product as significant differences in nutritional values could be observed between species and genotypes of the same species. These attributes are affected mainly by genetics, although environmental effects are to be considered as well. The outstanding antioxidant capacity of berries is well-known, hence they are used in the production of such products. It is worth mentioning though that berries are less ideal from the point of view of yield, harvest and shelf-life. Hence, to satisfy existing consumer demands cultivation of stone fruits with outstanding antioxidant capacity can be an alternative. Beside the fact that the antioxidant capacity of such fruits competes with those of berries, they possess other agricultural and economical benefits, as well.

The aims of my PhD work were as follows:

- Comprehensive analysis of the antioxidant capacity of stone fruit cultivars available in Hungary and genotypes that have not yet been included in the production.
- To examine which environmental parameters (year, location) might have an effect on the antioxidant capacity of such fruits to be able to suggest cultivars for the production of functional food.
- To choose species or cultivars which (based on the results of the *in vitro* antioxidant capacity analyses) can be the subjects of further analyses.
- Comparison of these cultivars using more antioxidant capacity assays, furthermore the analysis of their monomer anthocyanin, total polyphenol and flavonol contents.
- To evaluate the correlation of results obtained with the different methods.
- To identify polyphenols contributing to the outstanding antioxidant capacity and to measure their relative quantity in fruits of the assayed cultivars.
- To determine which compounds are responsible for the *in vitro* antioxidant capacity of the cultivars chosen.

MATERIALS AND METHODS

Plant material

Eight species (cherry plum, Japanese plum, peach, apricot, sweet cherry, sour cherry, blackthorn and other plums) and totally 138 genotypes of stone fruits were analyzed. Seven cherry plum, 16 Japanese plum, 12 peach, 29 apricot, 33 sweet cherry, 32 sour cherry and 9 blackthorn genotypes were involved in the experiments. Besides the endogenous factors, the effect of exogenic factors (like harvest year, region, position in the canopy) to the antioxidant capacity were also examined. For my thesis, data from 2006 to 2011 were used. For the examination of differences in antioxidant capacity of fruits from different regions in case of sour cherry genotypes the fruits were harvested in Újfehértó, Siófok (Hungary) and Skierniewice (Poland). In case of apricots, fruits were harvested in Balatonvilágos and Boldogkőváralja (Hungary).

Examination of influential factors on the antioxidant capacity of stone fruits

Fruits were halved, pitted and homogenized with blender (Bosch MMR0800, Stuttgart, Germany; 350 W, 4 °C, 2 × 2 min), then the homogenized fruit pulp was centrifuged (Mikro 22 R, Hettich Zentrifugen, Tuttlingen, Germany; 18750 g, 20 min, 4°C). For the measurements the supernatants were used. Samples for further analysis were kept in eppendorf tubes at -32 °C until use. Samples were analyzed in two parallels and in three replications.

Antioxidant capacity was determined by the FRAP (ferric reducing ability of plasma) method using a spectrophotometer at $\lambda=593$ nm [BENZIE and STRAIN, 1996]. For the measurement ascorbic acid was used as standard. Total phenolic content (TPC) was measured using Folin-Ciocalteu's reagent according to the method of SINGLETON and ROSSI [1965]. The soluble phenol content was calculated from a standard curve based on gallic acid concentration. The blue solution formed in the reaction was detected using a spectrophotometer at $\lambda =760$ nm.

The total antioxidant capacity, total monomeric anthocyanin (TMAC) and flavonol content of the sour cherry genotypes

For the measurements the samples were lyophilized (Scanvac CoolSafe™ 110-4, Lynge, Denmark; -110 °C, 3-4 days) and pulverized. The samples were stored in Falcon-tubes in dark until use. For the antioxidant capacity methods the lyophilized samples were extracted with Milli-Q water and for the total monomeric anthocyanin (TMAC) and flavonol content the samples were extracted with methanol:MilliQ:HCOOH (60:39:1 v/v%) solution. From each sample the extraction was carried out in three replicates. The samples were homogenized and placed for one hour in an ultrasonic bath. The extract were centrifuged (Mikro 22 R; 8000 g, 10 min, 4 °C) and the supernatant was transferred to another Falcon-tube. Samples were stored at -32 °C until use.

The total antioxidant capacity was determined using the TEAC method (Trolox equivalent antioxidant capacity) described by *MILLER et al.* [1993]. The colour change of the solution in response to the antioxidant compounds in the sample was detected at $\lambda = 734$ nm. The water and lipid soluble antioxidant capacity was measured by photochemiluminescence [*POPOV and LEWIN*, 1994; *POPOV and LEWIN*, 1996]. The measurement was carried out based on the description of Analytic Jena.

The total flavonol content ($\lambda=415$ nm) was determined using an aluminium-chloride method worked out by *WOISKY and SALATINO* [1998]. A pH differential method (pH 1,0 and pH 4,5) was applied to quantify the TMAC of the sour cherry genotypes [*LEE et al.*, 2005].

Identification of the major polyphenol compounds of sour cherry genotypes with HPLC-DAD-ESI-QTOF coupled system

For the identification of polyphenols a modified sample preparation described by *HARNLY et al.* [2007] was used. The lyophilized samples were extracted with methanol:MilliQ:HCOOH (60:39:1 v/v%) solution and daidzein (Extrasynthese, Genay Cedex, France) was used as internal standard. The samples were homogenized and placed for 40 minutes in an ultrasonic bath. The extract were centrifuged (Mikro 22 R; 8000 g, 10 min, 4 °C) and 2,5 ml supernatant was transferred to another Falcon-tube and diluted to 10 ml with Milli-Q water. Finally samples were filtered through a 0.22 μ m PTFE membrane before injection to the HPLC. From each sample two replications were prepared.

The separation and identification were carried out according to a method elaborated at the Corvinus University of Budapest, Department of Applied Chemistry [ABRANKÓ *et al.*, 2011; ABRANKÓ *et al.*, 2012]. The chromatographic separation was carried out with reversed-phase chromatography on Phenomenex Kinetex C18 column. An Agilent 1200 (Agilent, Germany) HPLC system including a diode array detector (DAD) was coupled to an Agilent quadrupole- time-of-flight mass spectrometer (Agilent 6530 QTOF, Germany), which was equipped with a dual spray ESI source. The instrument was operated in positive ionization mode.

Identification of the polyphenol compounds possessed with antioxidant capacity in sour cherry genotypes

The lyophilised samples were homogenised and the samples (1000 mg) were weighed into round-bottomed flask. The extraction of the fruit residue was performed by magnetic stirring with 10 ml ethyl acetate (4 times) under reflux. Each extraction takes 10 minutes. The ethyl acetate extract (40 ml) was evaporated to dryness using a rotary evaporator, the weight of the dry extract was measured and was dissolved in methanol. The residue after ethyl acetate extraction was delivered into 50 mL centrifuge tube and added to 50 ml with a mixture of methanol:MilliQ:HCOOH (60:39:1 v/v %). The sample was vortexed and after 1 hour of ultrasonic bath the suspension was filtered. 10 ml of the extract was evaporated to dryness using a rotary evaporator and dissolved in methanol. Both solutions were filtered through a 0.45 µm membrane filter before injection into the HPLC system.

For the measurements a method worked out at the University of Jaén, Department of Organic and Inorganic Chemistry was modified [Pérez-Bonilla *et al.*, 2006]. High-performance liquid chromatography (HPLC) analyses were performed by analytical RP-HPLC on a Waters 600E instrument (Waters Chromatography Division, Milford, MA, U.S.A.) equipped with a diode array detector, (Waters CapLC 2996, Waters Chromatography Division, Milford, MA, U.S.A.) All of the samples were analyzed two times, first in off-line then in on-line mode. A six-way switching valve (Waters Switching Valve, Waters Chromatography Division, Milford, MA, USA) was mounted between the HPLC column and the detector described above. A reaction coil (3-m long and 0.50 mm of internal diameter) was installed between the radical pump and the DAD. The free radical solution was prepared as describes by Exarchou és mtsai. [EXARCHOU *et al.*, 2006]. In on-line mode the valve also allows the eluted compounds to be directed to the reaction coil, in a second run, where both

antioxidants and radicals react one to another giving a decrease of absorbance at 734 nm detected in the DAD (“inverted” HPLC chromatogram).

RESULTS

Examination of factors affecting the antioxidant capacity of stone fruits

During our work we wanted to examine what factors (environmental and genetic) have an influence on the antioxidant capacity of stone fruits. For the examination of exogenous factors some representative species and cultivars were chosen. We liked to compare the antioxidant capacity of the samples harvested in different years, originated from different regions with different agricultural practice and soil or harvested from different parts of the crown.

The antioxidant capacity of 14 apricot genotypes were compared in two years and 12 sour cherry genotypes were analyzed in four years. Based on our results it is clear that the harvest year has no significant effect on the studied parameters. In case of three apricots and three sour cherry cultivars, we had the opportunity to compare the effects of the harvesting region on the *in vitro* antioxidant capacity. Similarly to former results [DRAGOVIC-UZELAC *et al.*, 2007; MUNZUROGLU *et al.*, 2003] small non-significant differences were found among the regions.

In case of seven sour cherry cultivars the antioxidant capacity of fruits from different part of the crown was compared. The average values measured with FRAP method were higher with 5 % in the samples collected from the outer part of the crown. The situation on the crown not influenced significantly the antioxidant capacity.

As a result of analyzing the *in vitro* antioxidant capacity of 138 genotypes in several years we found out that the peaches had the lowest antioxidant capacity, which was followed by cherry plums, apricots, Japanese plums, sweet and sour cherries. The highest average antioxidant capacity was characteristic for the blackthorn genotypes (Fig. 3).

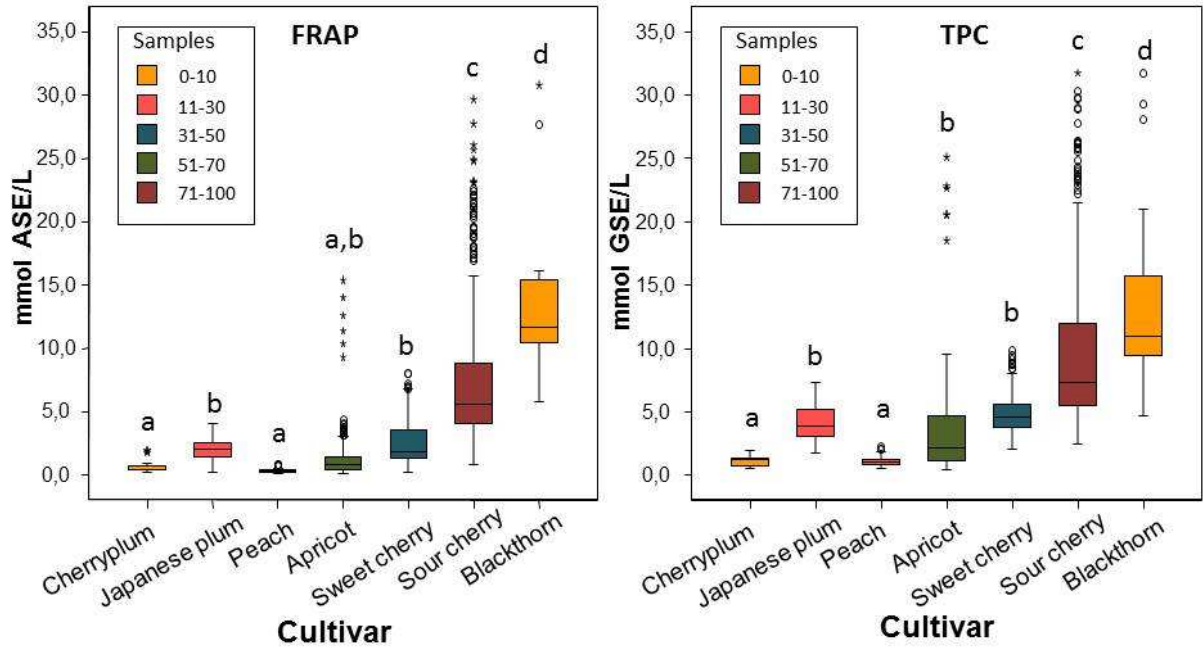


Fig. 3. The total antioxidant capacity (FRAP, mmol ASE/L) and total polyphenolic content (TPC, mmol GSE/L) of the stone fruit species. The same letters above boxes plots indicate no significant differences ($p>0,05$) based on Duncan-test.

In average, we can say that large variations are associated with the identification of genotypes of outstanding antioxidant capacity and total polyphenolic content. In case of apricots the FRAP value of Preventa reached the values of the earlier described red currants [Hegedűs et al., 2008]. The cultivation of the earlier mentioned Preventa is not a promising genotype because of its marked sensitivity to Plum pox virus and unbalanced productivity. However, this cultivar might be useful as breeding material for the improvement of the antioxidant capacity of future apricot cultivars. In general, the new French apricot cultivars like ‘Perle Cot’, ‘Sweet Cot’ and ‘Yellow Cot’ reached lower FRAP values while the old Hungarian landrace cultivars (‘Ceglédi arany’, ‘Ceglédi óriás’, ‘Gönci magyarkajszai’ and ‘Mandulakajszai’) possessed higher antioxidant capacities. In fruits of the Hungarian sweet cherry cultivars like ‘Germersdorfi 3’, ‘Katalin’ or ‘Linda’, lower antioxidant capacity was measured (**Fig.4**). The Ukrainian sweet cherry cultivars have darker skin and flesh and higher anthocyanin content [HEGEDŰS et al., 2013].

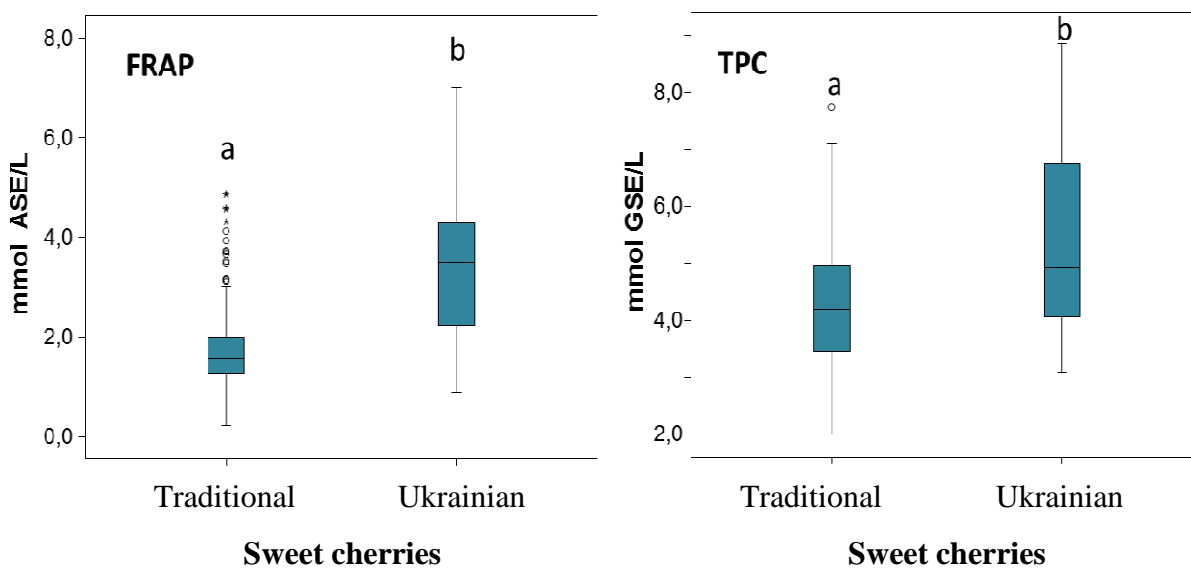


Fig. 4. Total antioxidant capacity (FRAP, mmol ASE/L) and total polyphenolic content (TPC, mmol GSE/L) of the Hungarian traditional and Ukrainian sweet cherry cultivars. The same letters on the boxes plots indicate non-significant differences ($p > 0,05$) based on Welch-test.

The ‘Újfehértói fürtös’ was described earlier as a cultivar with high antioxidant capacity [KIRAKOSYAN *et al.*, 2009] but compared with other Hungarian cultivars it was characterized by an average value. Generally, dark coloured fruits with higher anthocyanin content like ‘Csengődi’, ‘Érdi jubileum’, ‘Fanal’, ‘Oblacsinszka’ and ‘Sárándi’ were described to show higher antioxidant capacity as well. On the contrary, fruits of the traditional sour cherries (‘Debreceni bőtermő’, ‘Érdi bőtermő’, ‘Korai pipacs’ or ‘Pándy’) with light skin and flesh colours had lower antioxidant capacities. Based on these findings the outstanding antioxidant capacity of ‘Pipacs 1’ is interesting because this is an *amarella* type, pale sour cherry cultivar which was used for cakes as it did not paint the white cream. The outstanding *in vitro* antioxidant capacity of the ‘Pipacs 1’ cultivar was described first by our research team [PAPP *et al.*, 2010].

As a result we identified some cultivars/genotypes with outstanding *in vitro* antioxidant capacity. These genotypes might be used as raw materials for functional foods. These genotypes are the Preventa apricot, ‘Fanal’ and ‘Pipacs 1’ sour cherry cultivars, one black fruited sweet cherry clone and some Ukrainian sweet cherry cultivars as well as the S2 blackthorn genotype.

Identification of the major polyphenol compounds and comparison of the polyphenol composition of sour cherries

While the exact structure of the polyphenols effect their bioavailability (how much and in which form the components are able to be absorbed) [HOLLMAN *et al.*, 1999], we wanted to explore the differences in the flavonoid patterns of the Hungarian sour cherry cultivars. For the identification of the compounds an HPLC-DAD-ESI-QTOF mass spectrophotometer was used with ion source fragmentation, while the quadrupole was only operated as a collision cell.

Based on the database which was used in the present study [ABRANKÓ *et al.*, 2012] five quercetin-, one isorhamnetin-, four genistein-, four cyanidin- and one kaempferol-glicoside were tentatively identified. Four of them were confirmed by standards, namely the rutin (Que-dH-H), genistin (Gen-H), genistein (Gen) and the cyanidin-3-*O*-glucoside. Furthermore, with manual search chlorogenic acid, coumaric acid and flavan-3-ol derivatives were found.

Fruits can be divided into two groups based on the mayor cyanidin (Cya) derivatives accumulating in sour cherries. In the ‘Csengődi’ and VN-1 genotypes the mayor cyanidin-derivative is Cya-deoxihexoside (dH)-hexoside (H), while in others the Cya-dH-H-H is the dominant compound (Fig. 5).

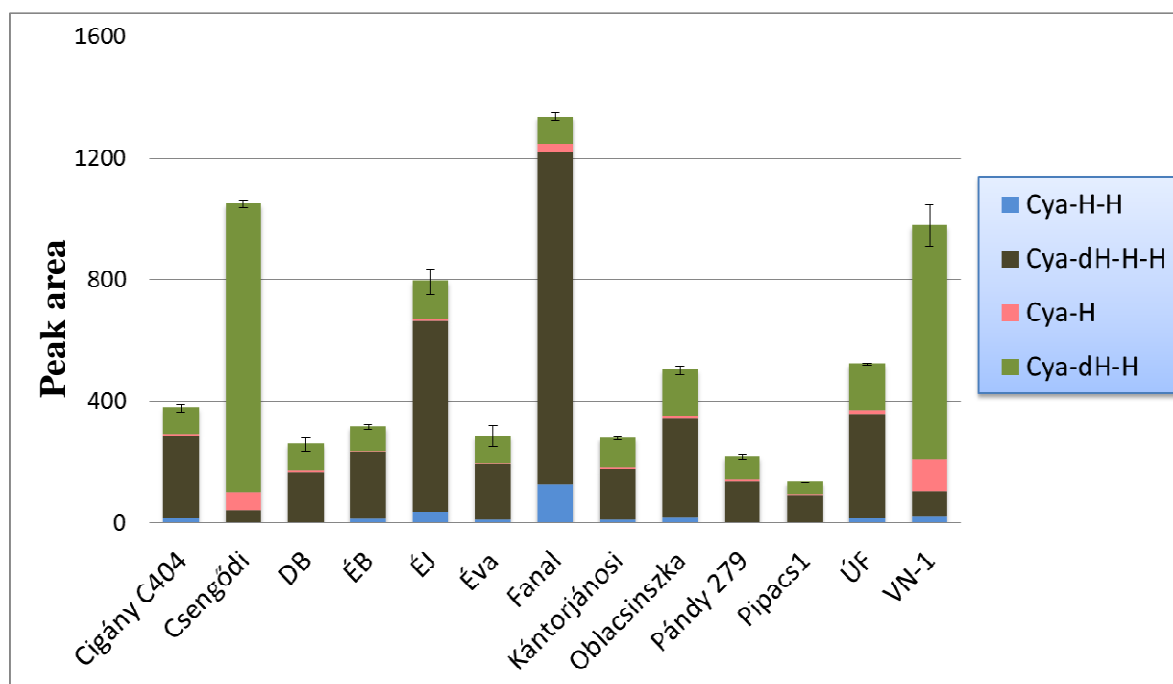


Fig. 5. The peak area of the tentatively identified cyanidin-derivatives. (DB: Debreceni bőtermő, ÉB: Érdi bőtermő, ÉJ: Érdi jubileum, ÚF: Újfehértói fűrtös)

Based on the quercetin (Que) pattern, three groups can be distinguished. In the majority of the samples the Que-dH-H, while in the ‘Fanal’ cultivar the Que-dH-H-H accumulated in the largest amounts. In fruits of ‘Érdi jubileum’ and ‘Oblacsinszka’ cultivars approximately equal amounts of the earlier mentioned two compounds were found (Fig. 6).

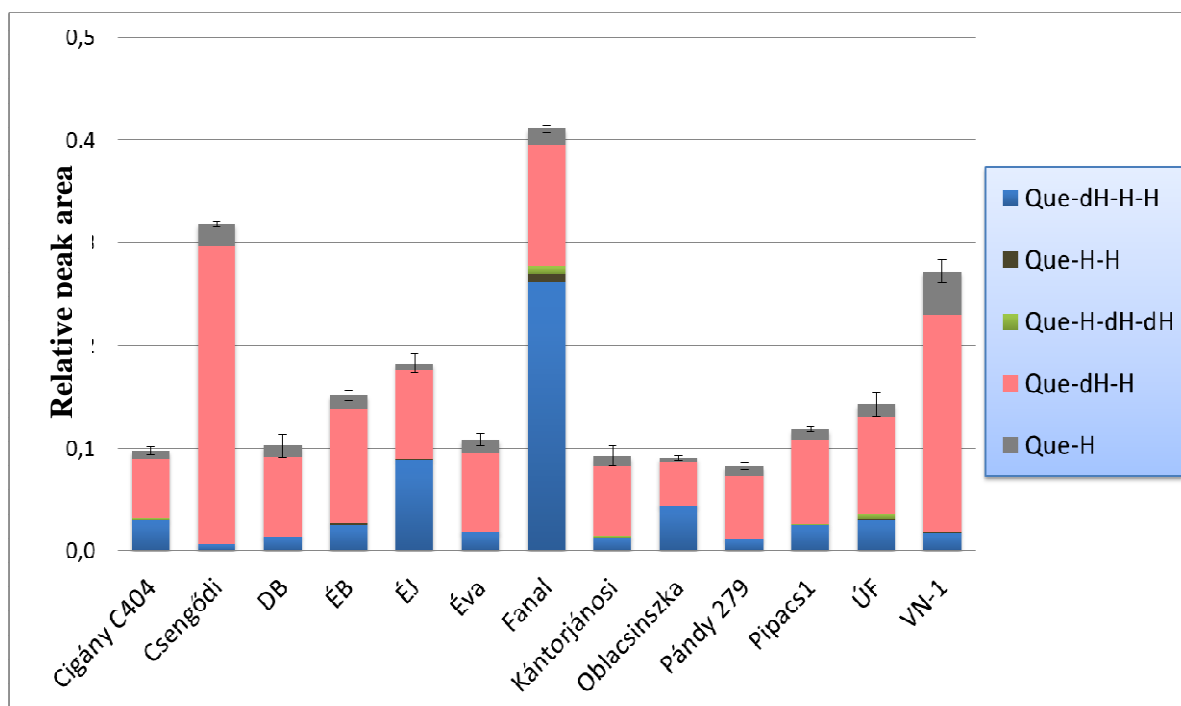


Fig. 6. The relative peak area of the tentatively identified quercetin-derivatives. (DB: Debreceni bötermő, ÉB: Érdi bötermő, ÉJ: Érdi jubileum, ÚF: Újfehértói fürtös)

The samples can be divided into two groups based on their chlorogenic acid patterns. In ‘Cigánymeggy C404’ and ‘Oblacsinszka’ sour cherries, the chlorogenic acid was found in larger amounts than neochlorogenic acid, while other samples were characterized by an opposite tendency (Fig. 7).

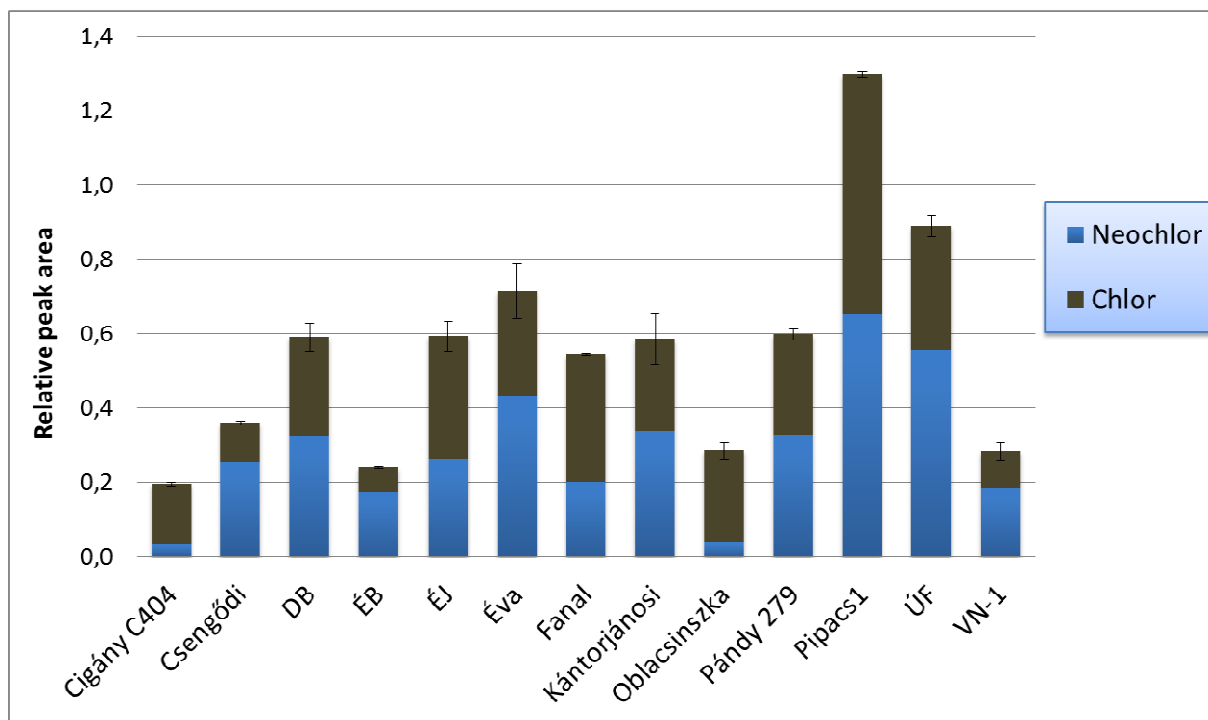


Fig. 7. The relative peak area of the tentatively identified chlorogenic acid-derivatives. (DB: Debreceni bőtermő, ÉB: Érdi bőtermő, ÉJ: Érdi jubileum, ÚF: Újfehértói fűrtös)

Five of the tested sour cherry genotypes contained genistein-derivatives in fruits under the limit of detection, while eight genotypes accumulated more. Among all, ‘Pipacs 1’ was highlighted because it contained significantly the highest amounts of genistein-derivatives.

Identification of the polyphenol compounds with antioxidant capacity in sour cherry fruits

The identification of the polyphenol compounds with *in vitro* antioxidant capacity was carried out in the Department of Organic and Inorganic Chemistry in the University of Jaén in Spain. For the experiment eleven lyophilized sour cherry samples (‘Cigánymeggy C404’, ‘Csengődi’, ‘Debreceni bőtermő’, ‘Érdi bőtermő’, ‘Érdi jubileum’, ‘Éva’, ‘Kántorjános 3’, ‘Oblacsinszka’, ‘Pipacs 1’, ‘Újfehértói fűrtös’ és VN-1) was used.

In the Department of Organic and Inorganic Chemistry of University of Jaén a method was developed earlier for the on-line measurements. In the first part of our work our aim was to modify this method and sample preparation for our samples matrixes. Later with the new on-line method the eleven sour cherries were compared and the compounds with *in vitro* antioxidant capacity were identified with ion trap mass spectrometry.

Based on the negative peak heights it can be assessed that chlorogenic acids, procianidins, anthocyanins were responsible for approx. 30 %, 20 % and 25-30 % of the antioxidant capacity, while the remaining compounds explained approx. 10 % of the antioxidant capacity of sour cherry fruits. The anthocyanins have greater role in case of the morello type cultivars. The observed differences in the flavonoid composition (characteristic chlorogenic acid- or cyaniding-derivatives) were confirmed by on-line, the iontrap and QTOF measurements.

RESULTS FOR PRACTICAL UTILIZATION

In Hungary, natural conditions are favourable for fruit production. After apple, the cultivation of stone fruits is the most noticeable in our country. Thanks to the breeders' efforts several cultivars are available; and wild genotypes and almost forgotten landraces further broaden the choice. In my opinion, finding and recognizing perspective genotypes will be a key factor, as there is a growing demand for special fruit-based products with increased health effects. During our work we intended to perform studies that are necessary for the development of such fruit-based products. This might help the selection of stone fruit cultivars/genotypes with outstanding health effects or can be used as raw material in functional breeding.

Though small differences were observed between production sites of Hungary and seasons, they do not have significant effects on the antioxidant capacity of fruits, as it has been reported before. However, it cannot be ruled out that besides the yield of fruit trees extreme weather conditions may also affect the contents of bioactive compounds.

The antioxidant capacity of stone fruits is mainly determined by the genotype. Based on our results it can be concluded that the production of fruit-based products rich in bioactive compounds must be based on a proper choice of cultivars/genotypes. Varieties named 'Kutuzovka', Preventa, 'Fanal' and 'Pipacs 1' are recommended for such products as raw materials.

In some previous studies, the high antioxidant capacity of sour cherry was explained by its high anthocyanin content. Sour cherries are also rich sources of other polyphenols characterized by in vitro antioxidant capacity, such as chlorogenic acid, quercetin, kaempferol, procyanidine or genistein derivatives. Significant differences were found among sour cherry cultivars regarding their polyphenolic composition. Our results might be the

starting point of new research programs regarding the bioaccessibility of polyphenolic compounds of sour cherries, as the absorption of such compounds is greatly influenced by their exact structure. Some of them are absorbed more easily, and can reach the organs more rapidly, while others need more time to take their effect.

In future, not only the highest content of bioactive compounds will be an important character but knowledge on the exact structure of polyphenols may be also useful. I am planning to complete my work with research activities that might help to understand better the health promoting effects of the worthily famous Hungarian sour cherries and other stone fruits.

NEW SCIENTIFIC RESULTS

1. Based on the analysis of Hungarian stone fruits the endogenous (genetical) factors influenced mainly the in vitro antioxidant capacity and in case of the tested genotypes small differences were found among the samples harvested from different regions and years.

2. As a result of analyzing the in vitro antioxidant capacity of 138 genotypes in several years we found out that the peaches had the lowest antioxidant capacity, which was followed by cherry plums, apricots, Japanese plums, sweet and sour cherries. The highest average antioxidant capacity was characteristic for the blackthorn genotypes. In average, we can say that large variations are associated with the identification of genotypes of outstanding antioxidant capacity and total polyphenolic content. We identified some cultivars/genotypes with outstanding in vitro antioxidant capacity. These genotypes might be used as raw materials for functional foods. These genotypes are the Preventa apricot, 'Fanal' and 'Pipacs 1' sour cherry cultivars, one black fruited sweet cherry clone and some Ukrainian sweet cherry cultivars like the 'Kutuzovka', 'Kodrinszkaja' and 'Dagesztanka' as well as the S2 blackthorn genotype.

3. We confirmed that the flavonoid patterns of the Hungarian sour cherry genotypes are different which may affect the bioavailability of the components.

- In the 'Csengődi' and VN-1 genotypes the mayor cyanidin-derivative is Cya-dH-H, while in others the Cya-dH-H-H is the dominant compound.
- In the majority of the samples the Que-dH-H, while in the 'Fanal' cultivar the Que-dH-H-H accumulated in the largest amounts. In fruits of 'Érdi jubileum' and 'Oblacsinszka' cultivars approximately equal amounts of the earlier mentioned two compounds were found.
- In 'Cigánymeggy C404' and 'Oblacsinszka' sour cherries, the chlorogenic acid was found in larger amounts than neochlorogenic acid, while other samples were characterized by an opposite tendency.
- Five of the tested sour cherry genotypes contained genistein-derivatives in fruits under the limit of detection, while eight genotypes accumulated more. Among all, 'Pipacs 1' was highlighted because it contained significantly the highest amounts of genistein-derivatives.

4. We demonstrated that chlorogenic acid-, procyanidin-, quercetin-, kaempferol-, isorhamnetin- and cyanidin-derivatives are responsible for the in vitro antioxidant capacity of

sour cherry genotypes. In addition, in fruits of 'Pipacs 1' four further compounds also play a significant role.

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PUBLICATIONS RELATED TO THE DISSERTATION



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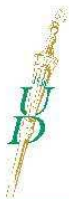
Candidate: Nóra Papp
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Doctoral School: Kerpely Kálmán Doctoral School of Corp
Production, Horticulture and Regional Sciences

List of publications related to the dissertation

Foreign language scientific article(s) in Hungarian journal(s) (4)

1. **Papp, N.**, Szőke, F., Szabó, Z., Nyéki, J., Stefanovits-Bányai, É., Hegedűs, A.: Preliminary evaluation of selected *Prunus spinosa* and *P. insititia* genotypes for their nutraceutical properties.
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2. Szikriszt, B., **Papp, N.**, Taller, D., Halász, J., Nyéki, J., Szabó, Z., Stefanovits-Bányai, É., Hegedűs, A.: Preliminary evaluation of breeding perspectives of Ukrainian sweet cherry cultivars: nutraceutical properties and self-incompatibility.
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10. Gergely, A., **Papp, N.**, Stefanovits-Bányai, É., Hegedűs, A., Rábai, M., Szentmihályi, K.:
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Total IF of journals (all publications): 4,371

Total IF of journals (publications related to the dissertation): 3,944

The Candidate's publication data submitted to the iDEa Tudóstér have been validated by DEENK on the basis of Web of Science, Scopus and Journal Citation Report (Impact Factor) databases.

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