Doctoral (PhD) thesis

ADAPTATION EVALUATION OF FOREIGN APRICOT CULTIVARS BASED ON THEIR FLOWER BUD DEVELOPMENT, FROST HARDINESS, AND FRUIT QUALITY

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1. INTRODUCTION

Apricot (*Prunus armeniaca* L.) is native to China, and it prefers warmer climate. However, the tradition of apricot growing in Hungary dates back several hundred years. It plays an important role in healthy diet, because the fruits have very valuable traits (high fiber, low energy content). It contains relevant amount of C-vitamine, B_1 and B_2 vitamin, and it have high potassium, calcium, phosphor and magnesium content. It also has high carotene content, which plays important role in maintaining the immune system.

Apricots fruits are well-sellable also in the international market. However, we have to meet the requirements of the market, to be competitive. In order to achieve good market position, we have to know the maturation processes and fruit quality parameters of the grown cultivars as detailed as possible.

Nowadays, one of the main aims of apricot breeding, besides enhancing the fruit quality, is to enhance the abiotic and biotic resistance of the cultivars. In Hungary, apricot can only be grown economically in some specific areas, due to its poor ecological adaptability and susceptibility to frost damage. The yield safety depends significantly on the frost damage of winter and springtime. Determining the frost tolerance of the overwintering organs is a very important aspect of the evaluation of apricot cultivars. Yield loss occurs frequently in case of unsuitable production site or cultivar use, resulting in large fluctuations in the annual yield of Hungary. The Hungarian assortment of apricot cultivars should be widened, which can be achieved by local breeding work, or by introducing foreign cultivars to the country. Cultivars having good frost and winter tolerance, long dormancy period, and excellent fruit quality are preferable for widening the assortment. Therefore, the freeze and frost hardiness of flower buds and flowers, and the schedule of microsporogenesis of newly-bred apricot genotypes should be examined in detail, as they are essential for the fruit development. Furthermore, the physical and chemical characteristics, quality parameters and health benefits of fruits should also be examined, as they are determining the acceptance of consumers, thus their suitability for growing.

During our three year research, the objectives listed above were targeted. Such foreign apricot cultivars were examined, about which we have very few experience or available research data.

2. RESEARCH AIM

At the beginning of our research work, I aimed to determine in detail the frost hardiness, microsporogenesis, maturation biology and fruit quality characteristics of foreign apricot cultivars, and based on these, confirm their suitability for growing in Hungary. Hungarian cultivars, grown for long in the country, were chosen for comparison. Besides the traditional methods, several more advanced labor methods were used.

Detailed aims:

1. Determining the frost hardiness of apricot cultivars, based on artificial freezing experiments.
2. To proove the vintage effect on the frost hardiness of flower organs by statistical analysis.
3. Classification of apricot cultivars based on their frost hardiness.
4. Determining the schedule and order of microsporogenesis for several years.
5. To monitor the change of fruit texture during maturation, and show the differences between the cultivars; to compare the applicable methods.
6. To analyze the fruit quality parameters of foreign and Hungarian apricot cultivars.
7. Determining the sugar and acid profile of apricot cultivars.
8. Modeling the connection between the flesh firmness and the soluble solid content of apricot cultivars.
9. Determining the ß-carotene and polyphenol content of apricot cultivars.

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

3. MATERIAL AND METHOD

3.1. The origin of the experimental samples

Samples were collected from the experimental field of the Department of Pomology, located in Soroksár. In the years of 2010/2011, the trees of the foreign cultivars were young, so samples were also collected from the apricot orchard of Vitamir Kft. located in Mór, which have similar conditions to Soroksár concerning the risk of frost damage. The city is located in the northwest region of Fejér shire, in the valley lying between Vértes and Bakony Mountains called Móri Trench.

3.2. The investigated cultivars

Altogether 20 apricot cultivars were selected for the investigations from the cultivar collection located in Soroksár. The frost hardiness was evaluated of the following cultivars: 'Sylvercot', 'Pinkcot', 'Goldrich', 'Sylred', 'Pisana', 'Laycot', 'Orange Red', 'Sweet Red', 'Veecot', 'Aurora', 'Bergarouge', 'Harlayne'. The process of microsporogenesis was investigated in the case of three Romanian (Ro) and five Nort American (Am) cultivars. These were the followings: 'Comandor' (Ro), 'Harcot' (Am), 'Harlayne' (Am), 'Harogem' (Am), 'Litoral' (Ro), 'Orange Red' (Am), 'Pinkcot' (Am), 'Sirena' (Ro). The fruit quality parameters of the following cultivars were investigated: 'Sylvercot', 'Pinkcot', 'Goldrich', 'Orange Red', 'Veecot', 'Aurora', 'Bergarouge', 'Harcot', 'Harogem', 'Litoral'. The following Hungarian cultivars were used as reference: 'Ceglédi bíborkajszi', 'Gönci magyar kajszi', 'Rózsakajszi C.1406', 'Budapest', 'Mandulakajszi'.

3.3. Determination of the frost damage susceptibility of flower buds and flowers by artificial freezing

Artificial freezing experiments were carried out in the wintertime dormancy period of three consecutive years: 2010/2011, 2011/2012, 2012/2013. Also in the springtime of 2011, 2012 and 2013, detailed assessments were made to determine the frost hardiness of flowers being in various phenological stages. The frost hardiness of the overwintering organs was determined by artificial freezing experiments too. A Rumed 3301 (Rubarth Apparate GmbH) type freezing chamber was used for the experiments. The degree of frost damage was evaluated after the buds were sliced, based on their browning. The browned tissues were considered to be damaged, while green tissues were considered to be intact. The frost tolerance was determined based on the lethal temperature to 50% plant tissue (LT_{50}) for each cultivar on every occasion.

3.4. Investigation of the microsporogenesis

Examinations were carried out in three consecutive years in the winter of 2010/11, 2011/12 and 2012/13. Fruiting twigs were collected from the trees in every week in the winter dormancy period, and the flower buds on their sides were examined. In every occasion, we examined the anthers of 8-10 flower buds per genotype. The phenological stage of microsporogenesis could be seen on the slides, and it was noted as well as its percentage. Six phenological stages were distinguished: archeosporium stage, string stage, pollen mother cell stage, tetrad stage, microspore stage, and the pollen stage.

3.5. Fruit analytical methods

The physical and chemical characteristics of the apricot samples collected on the experimental field were investigated in the analytical laboratory of the Department of Pomology. The following physical parameters were measured: fruit weight, three different kinds of fruit diameter (height, width, and thickness), flesh firmness, and refraction. The investigated chemical parameters were as follows: titrable acid content, sugar and acid profiles, phenol and ß-carotene content. Total polyphenol content was measured as described by Singleton and Rossi (1965), and it was expressed in gallic acid. The ß-carotin content was determined by the method of the KPKI (Canning Industry Research-Development and Quality Controll Institute).

3.6. Statistical analysis

The research data was analyzed by the IBM SPSS Statistics 20 program package. The lethal temperature to 50% plant tissue (LT_{50}) was calculated by linear regression modeling. In order to show the differences between the cultivars or to reveal vintage effect, based on the LT_{50} values of the dormancy and flowering periods two-way (cultivar, year) ANOVA was used with blocking, where the blocks were the dates of the examinations. The process of microsporogenesis was described with a sigmoid function. Analyzing the data of the physical and chemical parameters of fruits, one-way (cultivar) ANOVA, two-way (cultivar, year) ANOVA, or multivariate ANOVA (MANOVA) were used to compare the cultivars, or the data of different years. The connection between the soulable solid content (Brix°) and flesh firmness (kg/cm^2) was described with nonlinear regression model. The different flesh firmness measurement methods were compared based on the Pearson correlation coefficient.

4. RESULTS AND CONCLUSIONS

4.1. Frost hardiness of flower buds and flowers of apricot cultivars

4.1.1. Results of the experiments carried out in the wintertime dormancy period

The suitability of apricot for economic cultivation is affected significantly by the poor ecological adaptability of the species (Badenes et al., 1998). In Hungary, the most relevant problem is the harmful effect of low temperature (Szalay, 2003), which was confirmed by our results too. Frost damage may occur in the autumn, winter and spring; however, the greatest trouble is caused by the springtime frosts (Szalay, 2003; Surányi and Molnár, 2011). The frost hardiness of cultivars is determined by genetically heritable traits of the plant, thus there are huge differences between the cultivars (Pénzes and Szalay, 2003). Based on the experiments carried out in the winter dormancy period of all the three research years (2010/2011; 2011/2012; 2012/2013), most of the foreign apricot cultivars ('Aurora', 'Laycot', 'Sweet Red', 'Pinkcot', 'Sylvercot', 'Pisana', 'Sylred') were considered to be more susceptible to frost damage than the susceptible reference cultivar ('Ceglédi bíborkajszi'). The following cultivars were moderately tolerant to frost: 'Goldrich', 'Orange Red', 'Veecot', and 'Bergarouge'. Only 'Harlayne' was prooved to be resistant to frost, thus being the most resistant among the cultivars, while 'Aurora' was the most susceptible of all.

The environmental factors affect the frost hardiness of cultivars significantly, hence the development of the frost hardiness of cultivars might differ depending on the year or growing site (Pénzes and Szalay, 2003). Minor differences were experienced between the data of the three years. The frost hardiness of flowers gradually developed during the hardening. The intensity of hardening was influenced by the outer temperature. The flower buds lost their frost hardiness gradually in the second part of winter, the intensity of this decrease depended on the change of the weather. Based on the two-way ANOVA with blocking, it can be concluded, that no significant vintage effect could be shown ($F_{year}(2;90)=0,41$; $p=0,66$). The cultivar, however, had strongly significant effect ($F_{cultivar}(2;90)=27,89$; $p<0,001$), while no significant interaction were found ($F_{interaction}(4;90)=0,15$; $p=0,96$). Based on the Tukey post-hoc test the three reference cultivars had significantly different frost hardiness ($p<0,05$). There were low difference in the lowest lethal temperatures to 'Ceglédi bíborkajszi' measured in the wintertime of the three years. This value were -20,8 °C, -20,5 °C, and -20,2 °C in the winter of 2010/11, 2011/12, and 2012/2013, respectively. Thus in 2013 it was less resistant by 0,6 °C, than in 2011. The LT_{50} values of 'Rózsakajszi C.1406' also slightly differed in the three years.

Similarly to the susceptible cultivar this value (-23,3 °C) was the highest in the winter of 2010/2011. In 2013 it was less resistant by 0,4 °C, than in the year of 2011. In the second half of winter the frost hardiness of flower buds gradually decreased. In the beginning of January of the winter of 2010/2011, the difference between the LT_{50} values of the susceptible and resistance genotype was 2,5 °C, while in the end of march this difference was only 1,5 °C. However, in 2011/2012, in the most cold month the same 2,5 °C difference was experienced comparing the susceptible and resistant genotypes, it only decreased to 2,4 °C until the end of the hardening period. In contrast to this, in the winter of 2012/2013 the difference between the reference cultivars was less than at the beginning of the flowering period.

The winter hardiness of the scion might be influenced by the rootstock (Nitranski, 1977; Vaszily, 2012). The development of the frost hardiness of 'Sylvercot' was investigated on three different rootstocks (myrobalan, Missuri, C29), in the year of 2010/201. The LT_{50} values only slightly differed depending on rootstock. The date of 21th of February in 2011 was an exclusion, hence 'Sylvercot' on myrabolan could stand lower temperature than on C29 rootstock by 1,7 °C. The cultivar was the most frost resistant on myrabolan rootstock on nearly all dates of the investigation, and the most susceptible on C29 rootstock; however, the positive effect of the rootstock on the frost hardiness could not be proved.

The frost hardiness of the overwintering organs of the temperate-zone deciduous trees develops through several stages (Tromp, 2005). In the case of two standard cultivars we showed that the hardening process of flower buds can be divided into two distinct stages. The first period started long before the autumn leaf fall. In this stage the frost hardiness of flower buds increased fast in the beginning, than at slower rate, until it reached a value typical to the cultivar. The second stage of hardening took place during the period when the daily average minimal outer temperatures permanently felled beneath the freezing point. It was previously proved by the study of Howel and Weiser (1970) that the second stage of the hardening of apple only occurs if the temperature falls below 4,5°C. It was also proved, that sub-zero temperatures are necessary for the proper hardening of 'Redhaven', or the second stage of hardening does not develop (Szalay et al., 2010). Our data also suggest that the best values characterizing the genotypes will only be reached if the proper conditions of the hardening process have met. This means gradually decreasing temperature in the autumn, than after the first stage of the hardening process permanently sub-zero temperature, which lets the second stage of hardening to occur.

4.1.2. Results of the experiments carried out in the flowering periods

In three consecutive years the frost hardiness of the generative organs of three apricot cultivars were investigated by artificial freezing experiments. The frost hardiness was evaluated by the phenological stages.

In the flowering period the frost hardiness of the generative organs depends on the phenological stage. The more advanced the penological phase is, the more resistant the cultivar (Pénzes and Szalay, 2003). The same tendency could be shown in all three flowering periods. It can be concluded based on the two-way ANOVA with blocking, that there were significant effect of both the vintage and the cultivar ($F_{year}(2;39)=81,97$; $p<0,001$; $F_{cultivar}(2;39)=241,92$; $p<0,001$). Moreover, the interaction was also significant ($Finteraction(4;39)=4,9$; $p<0,01$). Because of the significant interaction, the cultivar effect was analyzed by year, while the vintage effect was analysed by cultivar. Based on the Tukey post-hoc test the frost hardiness of all the three cultivar differed from each other significantly in all three years ($p<0,05$). Furthermore, in the case of 'Ceglédi bíborkajszi' and 'Gönci magyar kajszi' the results of all the three years differed from each other significantly, while in the case of 'Rózsakajszi C.1406' there were no significant difference between the results of 2012 and 2013, which suggests that the frost hardiness decreased in a slightly lowered rate.

4.2. Microsporogenesis of the apricot cultivars

The schedule of microsporogenesis is strongly influenced by the environmental factors, primarily by the temperature (Szalay, 2008), which causes the vintage effect. This was confirmed by the results of our research, carried out with nine cultivars for three years. However, the cultivars followed each other in the same order in all the three years, proving that every phenological process is genetically regulated. Therefore, we can put the cultivars in order with high reliability based on the end of the dormancy period of their flower buds, and their mirosporogenesis, even if we have data for only few years. Before introducing new cultivars to the growing, we have to know their suitability to the region of production. Investigating the phenological processes gives useful data for this. In a specific production site, the success of growing can trustfully estimated on the basis of phenological experiments, if we use reference cultivars which have been cultivated for a long time, thus have well-known frost and winter hardiness.

To conclude our results we put the cultivars in order based on the schedule of microsporogenesis. In all three years the same order was concluded. This order can be considered to indicate the yield safety too. The dormancy period of the flowers of the first cultivar in the order, 'Pinkcot' had already ended in 10th to 25th of January, while of the last cultivar 'Harlayne' it had ended in 5th to 10th of February. The flower bud developments of three investigated cultivars were faster than of the reference cultivar. These were in order: 'Pinkcot', 'Orange Red', and 'Harcot'.

Because of their fast flower bud development in the winter, growing these cultivars in Hungary bears a relative high risk compared to 'Gönci magyar kajszi'. Those which have slower flower bud development than 'Gönci magyar kajszi', therefor, can be grown with greater safety. These are the followings in order: 'Litoral', 'Harogem', and 'Comandor', 'Sirena' and 'Harlayne'.

4.3. Market value defining characteristics of apricot cultivars

The buying decision of customers is mainly influenced by the size, color, and shape, the appearance of fruits, however, these characteristics do not guarantee the good taste and texture of fruits (Azodanlou et al., 2002). Besides the above mentioned characteristics, the proportion of sugars and acids has a key role too, as they are responsible for the harmonic taste of fruits (Parolari et al., 1992).

4.3.1. Weight and size parameters

The international market have more and more strict requirements concerning apricot fruits, and only the excellent quality, large-sized, and well-storable fruits are demanded. According to Pedryc and Hermán, (2011) apricot fruits can only be considered large-sized, if they are more heavy than 60 g, or they exceed 50mm in diameter. The minimal requirement on the fresh market is 40 mm avarage fruit diameter. Based on our results, the following four apricot cultivars produced larger fruits than 60 g, in both years of the study (2011, 2013), in all the three maturation stages (70%, 80%, 90%): 'Budapest', 'Goldrich', 'Pinkcot', 'Sylvercot'. In 2013, the fruits of 'Bergarouge' and 'Harcot' were also more heavy than 60g. Similarly to other researchers, significant difference could be shown between the cultivars and the years (Asma et al., 2005; Cociu, 2006; Ruiz and Egea, 2008; Bureau et al., 2009; Farina et al., 2010; Roussos et al., 2011). The size of apricot fruits is increasing significantly during the maturation process (Surányi and Molnár, 1981, Szalay, 2003; Farina et al., 2010; Németh, 2012). In our study the development of fruit weight were examined in three different maturation stages (70%, 80%, 90%). Similarly to the above mentioned researchers, growing tendency was experienced as the maturation was proceeding, in the case of all investigated cultivars.

Besides its weight, the size of the fruit is characterized by further parameters too (height, width, and thickness). For the investigated cultivars we have defined these parameters too; however, comparision was made based on the width values, as this is the largest diameter of the fruits, and this parameter is used for the classification during the postharvest handling. Those cultivars, which were considered to be large-sized based on their weight, did also exceed 50mm in diameter, with the exclusion of 'Goldrich'. All the cultivars exceeded the 40 mm minimum diameter, excluding 'Aurora' in 2011, in the first two maturation stages (70%, 80%). Significant difference between the cultivars and years could also be shown in the case of this parameter too. During the maturation progression these parameters were increasing too. Similar tendency was shown by Farina et al. (2010) and Németh (2012).

4.3.2. Comparative evaluation of the flesh firmness of the apricot cultivars

Fruit firmness is a basic quality trait of apricot fruits (Bassi et al., 1992). It defines the postharvest handling, the shipping and the storability of the fruit. The texture of apricot fruit becames more and more soft during the maturation process (Szalay and Balla, 2003; Kovács et al., 2008; Farina et al., 2010; Hitka, 2011). The same tendency could be shown by our research. The flesh is not equally firm on the sunny and shady sides. Based on our research data, all the cultivars had more soft flesh on the sunny side of the fruit, in all years of the study. Various apricot cultivars were examined by Szalay and Balla (2003) at 90% maturity. They measured higher flesh firmness values on the shady side. In 2011 'Goldrich' and 'Veecot'. In 2013 'Orange Red' and 'Veecot' had outstanding flesh firmness values at 70% maturity.

In 2011, we examined the development of flesh firmness of four Hungarian apricot cultivars, during the maturation process, with various methods. In all cases, lower flesh firmness values were measured with the hand penetrometer, than with the TA44 conical shaped probe. This difference even exceeded 15%. The flesh firmness was also examined with a needle shaped probe (TA9), as the third method. However, similar tendencies were shown with all the three methods. Significant correlation was shown with the Pearson correlation coefficient between the data of the hand penetrometer and of the TA44 probe (R^2=0,993; $p<0,001$); and the data of the hand penetrometer and of the TA9 needle shaped probe (R^2=0,925; $p<0,001$). Furthermore, strong correlation was shown between the two probes too (R^2=0,946; $p<0,001$). Based on these, all three methods can be considered to be suitable for the determination of fruit flesh firmness, and for following the developement of flesh firmness during the maturation process. Statistically more strong correlation could be shown between the data of the hand penetrometer and of the TA44 conical shaped probe, than between the hand penetrometer and the TA9 probe, however, the difference between the strenght of correlations was not relevant. Thus, we carried out comparative analysis on the data of the hand penetrometer and of the TA9 probe, measured at 90% maturity. Neither in this time could strong correlation be shown between the two methods by the Pearson correlation coefficient (R^2=0,65; $p>0,5$). Based on these, we came to the conclusion, that at 90% maturity, when the fruits are already more soft, as it is less destructive, the needle shaped probe gives more precise data than the hand penetrometer. This hypothesis was also confirmed by the fact, that at 80% and 90% maturity with more firm flesh, all three methods resulted in statistically similar data. In line with the softening of the flesh texture, at 90% maturity the measurements with the TA9 probe showed higher values, than the (Magness Taylor type) hand penetrometer measurements in the case of all cultivars. Therefore, we can conclude that at the end of the maturation process, the TA9 probe is more suitable for scientific research works, and gives more precise data.

Those cultivars which had the most firm flesh in our study were all foreign cultivars. The fruit flesh of ‘Hargrand’, ‘Harogem’, and ‘Laycot’ was outstandingly high at 70% maturity (15-16 kg/cm^2), and they were softening more slowly during the maturation process compared to the fruit of the Hungarian cultivars. These cultivars are suggested for compote production. Among the foreign cultivars, ‘Harlayne’ and ‘Veecot’ had soft flesh, similarly to the Hungarian cultivars. The following cultivars can be recommended for jam or puree production due to their soft fruit flesh: ‘Budapest’, ‘Ceglédi arany’, ‘Gönci magyar kajszi’, and ‘Harlayne’.

4.4. Inner quality factors responsible for customer acceptance

4.4.1. Soluble solid and sugar content

The sugar content of apricot cultivars influences greatly the acceptance of customers. The soluble solid content of fruits in increasing during the maturation (Szalay and Balla, 2003). In the present study, we could show increasing tendency in the investigated cultivars too. In the case of all cultivars, on the sunny side of the fruits the soluble solid content of the flesh was higher. Furthermore, significant vintage effect was shown. Based on the literature, the average sugar content of apricot is between 1,57 and 11,85 % (Ghorpade and Hanna, 1995). In the cultivars, wich were investigated, much higher values were measured. In 2011 ‘Gönci magyar kajszi’, in 2013 ‘Aurora’ and ‘Orange Red’ had the lowest soluble solid content, at 70 % maturity (their values were around 11 to 12 %). Comparing our data with the results of foreign research works, we can conclude that the apricot cultivars produced in Hungary have higher sugar content than of those which have foreign origin. However, the Turkish cultivars are exclusions, as their brix° exceeded that of the Hungarian cultivars.

The main sugar in apricot is saccharose, the proportion of glucose and fructose is much lower (Szalay and Balla, 2003). In our study, the investigated cultivars also contained mainly saccharose. Based on the nutrition panel published by Souci et al. (2008), the saccharose content in apricot fruits is about 3600 to 5980 mg/100g, while the glucose content is about 950 to 2880 mg/100g. We measured higher saccharose content than this in seven of the investigated apricot cultivars. At 80 % maturity in 2011 and in 2013 the saccharose content were 5609 to 10303 mg/100g and 7911,4 to 17220 mg/100g, respectively. The glucose content was 1730 to 3929 mg/100g and 948 to 2035,7 mg/100g in 2011 and 2013, respectively. The latter is close to the data published by Souci et al. (2008). In 2011, ‘Veecot’ had outstanding saccharose content, and ‘Pinkcot’ had the lowest. In 2013, The highest saccharose content was measured in ‘Gönci magyar kajszi’, and the lowest in ‘Veecot’.

Duo to the high saccharose content of the investigated apricot cultivars, they should be consumed by diabetics cautiously.

4.4.2. Acid contentment and profile

Besides sugar content, acids have important role in consumers' acceptance. The acid content is decreasing during maturation (Szalay and Balla, 2003), what was also confirmed by our investigations. We got lower acid content values on the sunny side of the fruits, and higher ones on shady side. Souci et al. (1989) determined the average acid content of apricot fruit in 1,4%. The average of total acid content in the investigated cultivars in our study at 90% maturity was 0,3 to 2,2 %, and 0,5 to 0,8 %, in 2011 and 2013, respectively. The lowest acid content in all two years, and all three maturation stages was measured in the fruits of 'Orange Red', while the highest in 'Goldrich'.

Several kinds of organic acids can be found in apricot fruits. Contradictory data can be found in the literature about their acid profile. In the greatest amount the flesh of apricot fruit contains malic and citric acid, besides lower amount of succinic acid, based on Souci et al. (2008). However, in some cultivars the citric acid, in others the malic acid is the dominant based on the literature. In all of the cultivars we investigated the dominant acid was the malic acid. At 80% maturity, the proportion of malic acid was between 920 and 1671 mg/100g , in 2011; and between 1078,5 and 1798 mg/100g, in 2013. The citric acid content was 518,6 to 659,6 mg/100g, and 193 to 1334 mg/100g, in 2011 and 2013, respectively. In 2011 we measured outstanding malic acid content in 'Harcot'; similarly as in 'Pinkcot', in 2013. Based on the data, therefore it can be concluded that the dominance of malic or citric acid in the fruits is depending on the cultivar.

4.4.3. Connection between the soluble solid content and total acid content of apricot cultivars

The proportion of soluble solid and total acid contents is responsible for the harmonic taste of fruits. The higher sugar/acid ratio of fruits refers to higher quality (Gómez and Ledbetter, 1997; Ledbetter et al., 2006). The fruits of 'Orange Red' had the highest sugar/acid ratio in all two years, at all three maturation stages. The refraction values were low or middle of this cultivar; however, it was paired with very low acid content in all cases. Besides the high sugar content of 'Gönci magyar kajszi', it had high acid content too in both years; which gives excellent taste to this cultivar. Based on our results 'Harogem' had similar sugar/acid ratio.

4.4.4. Correlation analysis

There are huge differences between the apricot cultivars concerning how their quality parameters are changing during the maturation. We were searching for connection between the changing of flesh firmness (kg/cm^2) and soluble solid content (Brix°) changes of four new foreign cultivars ('Goldrich', 'Pinkcot', 'Sylvercot', 'Veecot') during the maturation process in two research years (2011, 2013).

As a reference cultivar 'Gönci magyar kajszi' was used. Inverse correlation was found between the refraction and flesh firmness values in the case of all cultivars. In both years, the correlation between the flesh firmness and soluble solid content of the fruits of 'Gönci magyar kajszi' or 'Goldrich' could be described by a negative saturation model, while logistic curve was used in the case of 'Pinkcot'. In the case of 'Sylvercot' and 'Veecot', the appropiate model was logistic model in 2011, and negative saturation model in 2013. Higher flesh firmness was measured in 'Gönci magyar kajszi' in 2011 than in 2013, however the refraction values were similar. The same tendency was typical in the case of the foreign cultivars, therefore it can be concluded that the flesh of apricot cultivars were more firm in 2011 than in 2013. The statement that the flesh firmness is decreasing and the soluble solid content is increasing during maturation is confirmed by the models.

4.5. Biologically active compounds of apricot cultivars

The fruit of apricot is a rich source of polyphenols and carotenoids, which are essential components for health preservation. In both years, the polyphenol content of 'Gönci magyar kajszi' was outstandingly high. The cultivars 'Sylvercot' and 'Veecot' had the lowest polyphenol contents in 2011 and 2013, respectively. In 2013 the investigated cultivars had higher polyphenol content than in 2011, with the only exception of 'Pinkcot' which had higher polyphenol content in 2011. The genotype itself is responsible for the total polyphenol development. Furthermore, the vintage effect on the total polyphenol content is also significant (Hegedűs, 2010). The results of our study similarly show significant cultivar and vintage effect.

The fruits of apricot have relevant ß-carotin content, which is around 0,6 to 6,4 mg/100g based on Souci et al. (2008). The ß-carotine content of the investigated cultivars is within this interval. In 2011, outstanding ß-carotine content was measured in 'Veecot' és 'Gönci magyar kajszi' at 80% maturity. In general, the fruits of the investigated cultivars contained much more ß-carotene in 2013 (approximately 1,5× more) than in 2011.

4.6. SUMMARY AND CONCLUSIONS

Apricot is one of the most frost-sensitive fruit species grown in Hungary. The yield security of apricot is greatly affected by the frost injuries of winter and springtime. There is a huge demand for apricot fruits on the international market, but only the excellent quality, appealing, well-colored, large-sized, well-transportable and well-storable fruits are competitive.

There were significant differences in the frost tolerance of the cultivars. Among the foreign cultivars 'Harlayne' had outstanding frost-tolerance, while the rest of them were moderately frost-tolerant, or frost-sensitive, in comparison to the three reference cultivars. These cultivars can only be suggested in the case of safe production site, which is free of risky low-altitude areas. No significant vintage effect could be concluded, only minor differences were experienced in frost hardiness, comparing the data of different years; however, the frost hardiness varied significantly depending on the cultivar. The frost hardiness of the flower buds developed gradually during the hardening. The intensity of training is influenced by the change of the outer temperature. In the second half of winter the flower buds gradually lost their frost hardiness. The decreasing tendency showed strong correlation with the change of the temperature.

In Hungary, the most serious problem is caused by the frost injuries in springtime, therefor in a three year period, we carried out artificial freezing experiments to study the changing frost tolerance of the three reference cultivars. Significant effect of vintage or cultivar could be shown, in the three years of the study.

On the basis of the microsporogenesis results, the cultivars were ranked in terms of the schedule of microsporogenesis. Almost the same order was observed in all three years, and this order can be regarded as indicative of the yield safety of cultivars. The end of endodormancy in the flower buds was recorded between January 10th and 25th for the first-ranking cultivar ‘Pinkcot’, but not before February 5-10th for the last cultivar, ‘Harlayne’. Three of the tested cultivars had faster flower bud development than the reference cultivars (‘Pinkcot’, ‘Orange Red’ and ‘Harcot’, in this order), indicating that their cultivation would be riskier than that of ‘Gönci magyar kajszi’ in Hungary, due to their rapid flower bud development in winter. Cultivars found to have slower flower bud development than ‘Gönci magyar kajszi’ (in the order ‘Litoral’, ‘Harogem’, ‘Comandor’, ‘Sirena’ and ‘Harlayne’) could be grown with less risk in Hungary.

The expectations of the international market for apricot fruits is getting to be higher, only excellent quality, large sized, well-transportable and well-storable apricot cultivars are in demand. Based on our results, the fruit weight of ‘Goldrich’, ‘Pinkcot’, ‘Sylvercot’, ‘Bergarouge’ and ‘Veecot’ meets the requirements of the market; these cultivars produced large sized fruits.

The transport, package, and storage of fruits are basically determined by flesh firmness, which is, hence, a very important physical parameter. Outstanding fruit firmness values were measured in the case of ‘Veecot’, ‘Orange Red’, ‘Laycot’, ‘Hargrand’, and ‘Harogem’. Based on the measurements, the rest of the foreign cultivars also had more firm flesh than the Hungarian cultivars. Three flesh firmness measurement methods were also compared. It was concluded, that the needle probe gives the most precise result in comparison with the other two kind of cylinder probes, thus it is more suitable for research studies.

The proportion of sugars and acids of fruits have a significant role in consumer acceptance, and is responsible for the harmonic taste of fruits. Based on our results, the Hungarian apricot cultivars have high sugar content at 90% maturity (‘Budapest’, ‘Gönci magyar kajszi’, and ‘Mandulakajszi’). Similarly high sugar content was measured in some of the foreign cultivars, such as the ‘Bergarouge’, ‘Harcot’, ‘Litoral’, and ‘Veecot’. On the basis of two-year data ‘Harogem’, ‘Litoral’, ‘Veecot’, ‘Sylvercot’, and ‘Goldrich’ have similar acid content in comparison with the Hungarian cultivars, or even exceeded their values. Higher sugar/acid ratio refers to higher fruit quality. Similarly to ‘Gönci magyar kajszi’, harmonic acid/sugar ratio was measured in ‘Harogem’. However the sugar content of ‘Orange Red’ was relatively low, it had very low acid content, resulting in an outstandingly high sugar/acid ratio.

High ß-carotene and polyphenol content have significant health benefits, thus they were also measured in case of four apricot cultivars. In both years we measured outstanding polyphenol and ß-carotene content in ‘Gönci magyar kajszi’. Among the foreign cultivars ’Veecot’ had high ß-carotene content, even higher than the Hungarian cultivars did. High polyphenol content was observed in ‘Pinkcot’, but only in the year 2011.

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

4.7. New scientific results

1. The frost hardiness in the dormancy period of the flower buds of twelve foreign and three Hungarian apricot cultivars was determined by artificial freezing method and linear regression modeling, and they have been classified into three groups with hierarchical cluster analysis.
2. The vintage effect on the frost hardiness of flower organs has been confirmed by statistical analyses.
3. By investigating the flower bud development of eight foreign and one Hungarian reference apricot cultivar being in the dormancy period, the schedule and order of microsporogenesis have been determined. Based on these, I proved the suitability for cultivation of five foreign apricot cultivars, under the ecological conditions of Hungary.
4. Comparing instrumental methods, I proved that the needle shaped probe is more suitable than the cylinder shaped for monitoring the changes in apricot fruit texture, and to distinguish the difference between the cultivars.
5. From the two contradictory statements in the literature, that one has been strengthened, which says that apricot fruits contain malic acid in the greatest amount.
6. I described the changes in the flesh firmness of five apricot cultivars in the function of the soluble solid content with a non-linear regression model, in two research years. I confirmed the truthfulness of the models by their regression diagnostics.
7. I determined the polyphenol and ß-carotene contents of three foreign apricot cultivars (‘Sylvercot’, ‘Pinkcot’, ‘Veecot’) for the first time, which are important for health promotion. The average polyphenol content of their fruits is one third than of ‘Gönci magyar kajszi’. The ß-carotene content of ‘Sylvercot’, and ‘Pinkcot’ is lower than of ‘Gönci magyar kajszi’, and that of ‘Veecot’ is equal to it.

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