SZENT ISTVÁN UNIVERSITY

INVESTIGATIONS ON FRUIT CHARACTERISTICS, RIPENING DYNAMICS, AND COLOUR STABILITY OF CONVENTIONALLY AND ORGANICALLY CULTIVATED SPICE PAPRIKA

Thesis of PhD Dissertation

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BACKGROUND AND AIMS

The cultivation and processing of red spice paprika (Capsicum annuum var. Longum L.) is based on centuries-old traditions in Hungary. The milled dried fruits are an important spice and natural colouring of food industry and gastronomy. The importance of its bioactive compounds has been the subject of scientific research since a long time.

Since the 1990s, the demand for Hungarian spice paprika and the cultivation have shown a significant decrease. In the background the cause-and-effect relationships are generated by economic, social, demographic and lifestyle changes. In Hungary, the organic cultivation of spice paprika appeared in the late 1990s and early 2000s. The market for organic products is characterized by dynamic growth, which is an opportunity to increase the profitability of cultivation and to strengthen the reputation of Hungarian spice paprika.

There are very few research papers on the organic cultivation of Hungarian paprika. At present, conventional breeds are available, including resistant or tolerant varieties. Agrochemical treatments that can be used in bio farms are considerably limited. Comparative studies are unavailable about the differences caused by the conventional large-scale technology and organic farming.

The stability of natural colouring agents that determine the quality and commercial value of paprika is significantly limited. The stability is influenced by the cultivation, agro-meteorological conditions, the bioactive compounds developed during the ripening of the crop, the parameters of the applied processing techniques and the storage conditions.

Delay of colour degradation may help to preserve the quality and commercial value of paprika powder stocks stored in processing plants. Consumers and food product manufacturers may prefer suppliers can offer raw materials containing stabilized useful constituents and provide longer shelf life period for their products.

In the processing of spice paprika, methods or antioxidant additives are not applied for the decreasing of colour loss. Maintaining the traditional quality of spice paprika is an important requirement, so the applied methods should not change the original characteristics of the milled paprika.

It is not a common practice to examine the colour stability by accelerated shelf life test methods, based on reaction kinetic principles. This method could be used to estimate the loss of seasonal paprika quality in advance, and the results of product development work can be evaluated within a short period of time.

Aims of research:

- a comparative investigation of conventionally and organically cultivated resistant (Meteorit), tolerant (Mihálytelki) and high-colour, but disease-sensitive (Szegedi-20 and Karmin) paprika varieties in two vintage (2014 and 2015)
- comparative evaluation of fruits, based on morphological characteristics and dried fruit parts
- investigation of the ripening dynamics of fruits by analyzing changes in dry matter content, colorants and antioxidants, in green, brake, pale red, mature, and over-ripened stages
- colour content stability of processed (dried and ground) paprika pods during storage
- developing an accelerated colour stability test method, that approaches the changes occur during regular storage conditions

- reduction of colour loss in paprika powders using cold-pressed spice paprika seeds oil (as "no foreign" additive), and comparison of oil efficiency with antioxidant additives

MATERIALS AND METHODS

Overview of the experiment, test and data evaluation methods

I. Cultivation of conventional and organic spice paprika in 2014 and 2015		
sub-Tasks	**Location**	**Collected data**
Production of conventional experimental raw materials, collection of samples	Gorzsai Mezőgazdasági ZRt., Hódmezővásárhely	Cultivation methods, Meteorological data, Characteristics of fields Plant characterization, Photos
Production of organic experimental raw materials, collection of samples	Rubin Spice Paprika Processing Ltd., Organic fields in Balástya	

II. Examination and evaluation of conventional and organic pepper fruits (2014-2015)		
sub-Tasks	**Parameters**	**Statistical Methods**
Examination of morphological characteristics (mature, fresh fruits)	pod weight, length, diameter, stem length	ANOVA (3 factors), Impact of factors (η^2), Correlation Analysis
Processing of samples (over-ripening, drying, grinding, storing)	---	
Investigation of pod parts (dried, mature crops)	pericarp, seeds, peduncles and placental % (m/m)	
Ripening dynamics tests (dried green, break, pale red, ripe, and post-ripened samples)	Dry matter content	Function analysis, Dynamic indicator, ANOVA (3 factors), Impact of factors (η^2)
	Colour content (ASTA)	
	Carotenoids (HPLC)	Function analysis, Dynamic indicator, ANOVA (3 factors), Impact of factors (η^2) PCA
	L-ascorbic acid, α-, β-,- γ-tocopherol (HPLC)	

III. Storage experiments		
sub-Tasks	**Parameters**	**Statistical Methods**
Evaluation of the colour stability of conventional and bio paprika powders	Colour content during warehouse storage	Reaction kinetic calculations, ANOVA (3 factors), Impact of factors (η^2)
Developing light-accelerated shelf life test (samples of 2014)	Colour content, during provocation and warehouse storage	Reaction kinetic calculations, Regression function analysis
Evaluation of the accuracy of the accelerated test (samples of 2015)	Colour content, during provocation and warehouse storage	PME (%), RMSD, CV_{RMSD} (%), Linearity
Alternative colour stabilization test (paprika seed oil, tocopherol and rosemary extracts)	Colour content, light-accelerated shelf life test	Application of shelf life estimation model, ANOVA

Varieties and materials used for the experiment

For the analysis of fruits parameters and ripening dynamics we used green, break, pale red, ripe, and post-ripened fuits of Szegedi-20, Meteorit, Mihálytelki, and Karmin varieties produced by conventional and organic cultivation technologies. Samples were collected from the beginning of August to the second week of September, as the ripening progressed.

For alternative colour stabilization experiments, a conventional and bio Meteorit fruits from the last harvest of the 2015 vintage (October) and sun-dried pepper paprika produced in China were used. The milled paprika lots were treated in four ways: tocopherol antioxidant (0.2%), rosemary extract (0.2%), and cold pressed spice paprika seeds oil (3% and 6%).

Characterization of production fields

In the conventional production site, the main type of soil is meadow soil, Arany- number (KA) 62, pH 7.21, and humus content 2.6%. The nutrient supply of the soil is moderate in nitrogen (14mg/kg nitrite + nitrate), phosphorus is very good (188mg/kg P_2O_5), potassium is medium (352mg/kg K_2O).

In the bio-production site, the soil type is sand, Arany- number (KA) 26, pH 7.5, humus content 1.29%. The nutrient supply of the soil is good in nitrogen (7.8 mg/kg nitric nitrate + nitrate), phosphorus is good (241mg/kg P_2O_5) and potassium is good (203.7mg/kg K_2O).

Meteorological data

In the growing season of 2014, average monthly temperatures were lower than the average of the previous 5 years. The cumulated temperature was 3440°C from April to the end of September and the numbers of hot days (≥30 ° C) were 28. In May, July and September, a large amount of precipitation fell. From April to the end of September, in the conventional areas 621.7 mm of precipitation were registered, and 585.1 mm in the organic areas, while the average of the last five years was 276.2 mm. The cumulative hours of sunlight (1567 hours) were behind the average of the previous five years.

In the growing season of 2015, the average monthly temperature in August and September was more favourable than the average of the previous 5 years. The heat sum (3464°C) was similar to the previous year, but the number of hot days was nearly twice (54). On the organic fields, the rainfall (276mm) was similar to the average of the previous 5 years, while in the conventional area 26.8mm more rainfall was registered. The cumulative hours of sunlight (1706 hours) was 139 hours more favourable compared to the 2014 growing season.

Cultivation technology

On conventional fields, the pre-crop was autumn wheat. Ploughing and disc tillage soil preparation was carried out in September-October, and then the soil was broken up and levelled with harrow in spring. The fertilization plan was based on the MÉM-NAK instructions. The fertilisers (100% of phosphorus and potassium demand) were added to the soil during the autumn tillage. The sowing was carried out in late March- early April, with a density of 4.52-5.45 kg/ha seeds. The chemical weed control (Panterra 40EC , Devrinol 45F, Command 48EC), the cultivating and mechanical weeding, fertilization (Amalgerol, Csöppmix 3) and the chemical plant protection treatments (Cuproxat FW, Teppeki, Steward) were designed and carried out for the needs of spice paprika. Irrigation was not applied.

On the organic filed the pre-crop was rye, which was used as green-plant manure. It was broken down then ploughing into the soil together with organic animal manure at the end of March. The growing of paprika seedlings (April-May) was in greenhouse. A plant protection treatment was carried out with Cuproxat fungicide. The planting was carried out at the end of May / early June. During cultivation, in addition to manual mechanical weed control, plant protection treatments were also carried out with the Cuproxat fungicide approved in organic farming. A micro-spraying irrigation system was installed in the area; water supply was from an artificial lake.

Accelerated shelf life test (ASLT)

A light chamber was built for accelerated storage experiments, based on photochemical effects. A lockable box made of white furniture; on the top of box fluorescent lamps with a light intensity control switch were mounted. The light source consists of 2 Oshram Biolux T8 daylight type 30W 6500 K fluorescent lamps. The light intensity (6000, 4000, 2000 lux) was precisely adjusted using the instrument. The samples to be tested were poured into glass Petri dishes (90mm). The dishes were sealed to eliminate the effects of water content (and water activity) change. The control samples were placed in protective packs and stored at a temperature of 18-20 ° C.

Data processing and statistical methods

In the ***ANOVA***, vintage, cultivation method and variety factors were taken into consideration. Effect size (η^2) was calculated, which indicates proportion of the total variance associated with a factor (or interactions).

Pearson's ***correlation analysis*** was used to investigate the correlation between morphological parameters and dried crop parts.

To determine the best ***regression-function of the ripening changes***, we took into account the results of the statistical tests of the fitting (R2, adj. R2, F-test of regression, t-test of regression parameters).

In each ripening phase, the ***dynamics*** of parameters were expressed by an average daily accumulation (or decrease) rate:

$$D_y = \frac{Y_{f2} - Y_{f1}}{t_{f2} - t_{f1}} \quad (\mathrm{y \cdot day^{-1}}),$$

where Dy is the rate of dynamics, Y_{f1} and Y_{f2} is the investigated parameter at the sampling times of two successive maturation states (t_{f1}, t_{f2}).

Based on the carotenoid colour compounds and antioxidant profile, the ***Principal Component Analysis*** (PCA) was used to determine the groups of observations (paprika samples). The importance of the components in pc was determined using the $a_{ij}^2 \geq r_{5\%}$ criteria.

During storage experiments, the colour stability analysis was based on ***reaction kinetic calculations***. Based on the data of 2014's samples, ***empirical estimation model*** was established with the help of regression analysis. The model enables the extrapolation of the results of the accelerated test to the regular storage conditions. The independent evaluation of the estimation was performed by bias (***PME%***), root mean square deviation (***RMSD***), variation coefficient (***$CV_{RMSD\%}$***) and linearity.

RESULTS

The cultivation of *Meteorit* and *Mihálytelki* varieties on conventional and bio-fields was considered productive in both years. *Meteorit*'s resistance to diseases and *Mihálytelki*'s tolerance were clearly appeared. In the organic Meteorit plantation the numbers of fruits were higher by 31% in 2014 and by 12% in 2015, than in the conventional one. There was a different tendency in the Mihálytelki plantation since the number of crops was more favourable on the conventional field by 24% in 2014 and by 10% in 2015. The cultivation of varieties without resistance or disease tolerance (*Szegedi-20* and *Karmin*) is not efficient with the organic technology, even if the meteorology conditions are favourable. In addition to the extensive disease-symptoms, there was a large lack of yields.

The morphological parameters of the fruits were primarily determined by the variety. The cultivation method did not affect ($p > 0.05$) the development of fruits weight, length, and diameter and pedicle size. This result was expected due to the unique properties of the varieties involved in the experiment. The *Meteorit* variety produced pods of outstanding weight (33.7-36.0g) compared to other varieties, independently the effect of vintage and cultivation method ($p > 0.05$). The fruit length and diameter were also larger, than in other samples. Meteorit pods were followed by the Mihálytelki and Karmin fruits (26.29g and 24.65g weigh, 107.1 and 101.9mm in length, 23.7 and 22.9mm diameter, 2.4mm and 2.3mm pericarp thickness). The lowest values of the morphological parameters were measured in the case of Szegedi-20 paprika (22.95g weight, 102.0mm length, 22.1mm diameter, 2.2mm pericarp). Generally, the 2015 fruits parameters were significantly below the data from the first year of the experiment. It could be stated that the weight and size of the bio paprika fruits were smaller than the conventional ones in 2014. In the following year, contrary trends were observed, as the data of conventional pods were less favourable. Correlation analysis showed that, the larger fruit weight was resulted by the thicker pericarp ($r = 0{,}652$, $p < 0{,}001$) and the fruit diameter ($r = 0{,}625$, $p < 0{,}001$), while the length had less effect ($r = 0{,}554$, $p < 0.001$). The pedicel length did not correlate with the other morfology data ($r = 0.214$ to 0.373).

The dried pericarp and the seeds are the most valuable parts of spice paprika; their amount essentially influences the quantity and quality of the final products. The vintage, as main effect, explained a larger proportion of total variances of both parameters ($\eta^2_{\text{pericarp}} = 49\%$, $\eta^2_{\text{seeds}} = 51.7\%$) than the other factors. The quantity of dried pericarp expressed as the average of cultivation and varieties, was less in 2014 (60.91%), than in 2015 (67.37%). The seed content was higher in 2014 (22.38%), than in the second year of the experiment (16.53%). The two parameters are correlate inversely to each other. Correlation analysis showed that the amount of pericarp expressed as a percentage by weight is strongly correlated with the seed content ($r = -0.881$, $p < 0.001$), and with the placenta ($r = -0.735$, $p < .001$), whereas it is correlated with the pedicel.

In the ripening process (biological- and technological post-ripening) the changes in ***dry matter content*** of the spice paprika samples are characterized by a third degree polynomial regression function. Significant changes occurred during the colour transition period of green-break and the post-ripening. The dynamics of change was basically influenced by the vintage factor. The cultivation methods had little effect on the changes, but conventional technology had a beneficial effect, due to lack of irrigation.

The changes in ***total extractable colour content (ASTA value)*** of the spice paprika samples are characterized by a symmetric logistic regression function. The very low initial colour content (8.9-22.8 ASTA) of green fruits can be attributed to yellow non-esterified carotenoids. In the pale red-red transition period the curves had inflection points, indicating the maximum rate of accumulation of colour. The dynamics of change was basically influenced by the varieties factor (η^2=45,7%), followed by the vintage and cultivation method (16,6-21,0%). In the main ripening phase, the most intense changes were in the fruits of the conventional *Szegedi-20, Karmin* and *Mihálytelki* varieties, in 2015. Among the 2014's samples, the colour changes of conventional *Szegedi-20* and *Karmin* were outstanding. The *Meteorit* fruits had significantly the lowest dynamic indicators in both years. In the post-ripening phase, the accumulation rate of the colour content decreased drastically, the variance of the dynamic rate was strongly determined by the variety (η^2 = 44.9%). This was followed by the vintage*cultivation*variety interaction (19.3%) and the vintage (17.0%). The most intense colour accumulation was observed in *Karmin*'s fruits, followed by *Szegedi-20*, then *Meteorit* and *Mihalytelki*. The colour content of conventional paprikas expressed as the average of the vintage was 275.3 ASTA in the *Karmin*'s pods, 258.2 ASTA in the *Szegedi-20*, 230.5 ASTA in *Mihalytelki* and 178.1 ASTA in *Meteorit*. In the case of organic paprika, colour content was 224.2 ASTA in *Karmin*'s pods, 204.8 ASTA in *Szegedi-20*, 202.9ASTA in *Mihálytelki* and 175.0 ASTA in *Meteorit* ones. The parameter "A" of the logistic function showed higher estimated saturation levels than the colour content post-ripened fruits. This suggested that the crops would have reached these colour contents if the post-ripening is not interrupted. This means that the model can be used to estimate the theoretically available best colour content during the post-harvest operations.

In HPLC examinations, 55 types of ***carotenoid derivatives*** were identified from spice paprika samples, depending on the maturation state. In green paprika fruits only yellow non-esterified carotenoids were found: neoxanthin, violaxanthin, luteoxanthin, antheraxanthin, cucurbitaxanthin A, mutatoxanthin, lutein and β-carotene. The red carotenoids of spice paprika could not be detected when no colour changes were observed on fruits. Hierarchical PCA according to the ripening state showed that the observations (pepper paprika samples) grouped on the basis of vintage (along the first principal component) and cultivation method (along the second principal component. Based on the analysis of the main component weights it can be stated that the vintage effect changed the carotenoid-derivatives profile of the examined varieties. The differences arising from the cultivation processes were manifested primarily in the amount of components. The evaluation of maturation dynamics with curve fitting on the changes the total carotenoid, red / yellow colour ratios and esterification (non-esterified carotenoids, monoesters and diesters) derivatives groups have revealed further conclusions. In the favourable year of 2015, the accumulation of red and yellow color was faster and reached their maximum level earlier. In the majority of conventional samples, the formation of diesters was not complete. In the bio samples of 2015, the reactions of esterification were inhibited, than in 2014. During the post-ripening, the formation of red carotenoids became dominant against the yellow ones, and the esterification process became more intensive, than the formation of non-esterified compounds.

The ***α-tocopherol*** synthesis is characterized by a symmetric logistic regression function. In the pale break-pale red transition period the curves had inflection points, indicating the maximum rate of accumulation. The vintage factor ($\eta^2 = 33.6\%$) explained a significant proportion of the variance of dynamics, but the strength of the vintage*interaction was also significant (24.1%). It has been observed that, with slower colour accumulation, the rate of α-tocopherol synthesis is more intense. The post-ripened 2014 conventional *Szegedi-20* had the highest α-tocopherol content (762.58μg/g). There was no significant difference between the bio-fruits in 2014 (average 653.62μg/g, $p > 0.05$). In 2015, the highest concentrations of α-tocopherol were measured from the conventional *Mihálytelki* and bio *Szegedi-20* samples (586.53 and 577.84µg/g, p> 0.05). This was followed by the conventional *Szegedi-20* and *Meteorit* as well as bio *Karmin* (average 555.39µg/g, p> 0.05). The conventional *Karmin*, bio *Meteorit* and *Mihalytelki* had the lowest α-tocopherol content, without significant differences between them (mean 532.01µg/g, p> 0.05).

The ***β-tocopherol*** synthesis is characterized by a symmetric logistic regression function. This suggested that it did not participate as antioxidant against the oxidative damage or with only minimal activity. The concentration in post-ripened fruits (8.65-15.37µg/g) was low, compared to α-tocopherol.

The ***γ-tocopherol*** content decreased during the intense colour synthesis phase. The dynamics of loss was determined by the vintage (η^2 = 20.8%) and the interaction of factors (η^2 = 24.5%). The results of the 2015 vintage suggest that γ-tocopherol synthesis increased due to the intense colour formation, but the intensity of the use was higher. The concentration in the post-ripened and dried pericarp was between 4.38 and 9.54µg/g.

There were two intensive phases in the dynamics of ***L-ascorbic acid*** accumulation: the green-break red and the pale red-red transition. A decrease of 13-33% during post-ripening occurred, and the dynamics of use was determined by the interaction of the factors ($\eta^2_{vintage*variety}$ =32,8%, and $\eta^2_{vintage*cultivation*variety}$ =20,5%). The L-ascorbic acid content was more favourable with organic cultivation (mean: 12595.89µg/g), than in conventional (9865.47µg/g). This trend is due to higher initial values and higher intensity of synthesis.

The ***colour content degradation*** of the dried and milled paprikas is described by a zero-order kinetic model during storage. The variance of pseudo rate-constant of the reaction was mainly determined by the varietal factor (η^2 = 58.5%), but the effect of cultivation was also significant

(18.0%). According to the pseudo reaction rate constants, *Meteorit* and *Mihalytelki* varieties exhibited outstanding colour content stability (-0.122 and -0.169 $ASTA \cdot day^{-1}$). These were followed by *Szegedi-20* and *Karmin* (-0.206 and -0.225 $ASTA \cdot day^{-1}$). In the case of higher ASTA values the colour loss was faster. Regression analysis showed that a unit increase in initial ASTA is expected to increase the reaction rate by 0.00127$ASTA \cdot day^{-1}$.

In the photochemical ***accelerated storage experiment***, the colour content degradation is significantly accelerated. The pseudo rate constants (k) values were 9, 10-11 and 11-12 times faster at 2000, 4000 and 6000 lux illumination, compared to the regular storage in warehouse (0 lux). The relationship between light intensity (I) and shelf life (θ_s) can be described by a power-function regression relationship: $y_i = \beta_0 \cdot x_i \beta_1$, the linearized form is $\ln y_i = \beta_0 + \ln\beta_1 x_i$.

Based on the accelerated test, the expected shelf life at warehouse conditions can be estimated by the following empirical equations:

- to a certain ASTA value ([C]): $\Theta_{S[C]} = \dfrac{[C]-[C]_0}{-k \cdot I^b}$
- to a certain ASTA value loss ($[C]_{veszt}$): $\Theta_{S[C]loss.} = \dfrac{[C]_{loss.}}{k \cdot I^b}$

where b is the β_1 parameter of the regression equation, as the acceleration factor

With the determination and statistical evaluation of the bias (PME%), we demonstrated that the model gives overestimation. Using the mean values of the kinetic parameters and the correction with the bias, the difference between estimated and actual data was reduced to 1.00-1.07%. Improved accuracy was demonstrated by model performance indicators (RMSD, CV_{RMSD}%, and linearity).

Alternative colour stabilization procedures were investigated with accelerated storage (6000lux), using low-stability paprika powders (k = -

2,869 - -4,672 ASTA·day^{-1}). Among the additives, the tocopherol extract proved to be the most effective. The reaction rate constant in the supplemented bio powder decreased by almost half (48%), and in the conventional and in the sun-dried paprikas by more than half (60-61%). The shelf life $\theta_{s[100ASTA]}$ increased twice in the bio sample (275 days), while in conventional and import samples, 2.5 times (458 and 459 days). The rosemary extract also dramatically increased colour retention, but its efficiency was more moderate. Due to the supplementation with 6% of cold-pressed paprika seed oil, the bio paprika powder, the conventional and sun-dried powders kept their first-grade quality ($\theta_{s[100ASTA]}$) for 188, 293 and 261 days, respectively. This meant that the shelf life was 1.3-1.5 times longer than that of untreated samples.

NEW SCIENTIFIC RESULTS

1. With the experimental design of the dissertation I developed a complex examination and data processing system for the analysis of fruit yields and ripening dynamics.

2. Cultivation of varieties without resistance or disease tolerance (Szegedi-20 and Karmin) by ecological process is not a viable, in favourable year either. In organic farming, only resistant or tolerant spice paprika varieties can be used.

3. I have proved that with the help of curve fitting and analysis, it is possible to evaluate the ripening process, and the genotype features and properties can be evaluated. Furthermore, the effects of several factors (eg. vintage and cultivation processes) in ripening processes can be identified.

4. I demonstrated that γ-tocopherol was involved in the intensive colour synthesis (pale red-red transition) and L-ascorbic acid during the post-ripening process with significant activity to protect against oxidative damage. The dynamics of use was determined by the interaction of vintage, cultivation and variety factors.

5. In the 2014-2015 vintage years, I studied the conventionally and organically cultivated spice paprika varieties and the following scientific results were found:

5.1 the maximum rate of colour accumulation is found in the ripening phase characterized by the pale red- deep red transition, the dynamics is primarily influenced by the variety, while the cultivation and the vintage's effect are secondary

5.2. with organic cultivation, the ripening dynamics were significantly slower than with conventional method

5.3. based on PCA, variability can be identified in the carotenoid and antioxidant profiles, caused by the vintages and the cultivation processes

5.4. the kinetic parameters characterizing the colour stability of the powders were influenced primarily by the variety and secondly the cultivation process. The products with lower ASTA colour value have lower pseudo-reaction rate constants.

6. Based on the reaction kinetic principles, I developed an accelerated shelf life test method. I have proved that the process, along with the acceleration of colour degradation, also approximates the changes in organoleptic properties to the phenomena occurring during regular storage.

7. I have proved that the supplementation with of cold-pressed paprika seeds oil is considerably delay the colour degradation of paprika powders. However, the efficiency of the process is weaker than that of natural tocopherol and rosemary extract formulations.

CONCLUSIONS AND RECOMMENDATIONS

The application of diseases-resistant (Meteorit) or tolerant (Mihálytelki) spice paprika varieties are productive in the organic farming. However, in order to improve the yield, need adequate nutrition-supply experiments, which fulfil the requirements of organic farming. Varieties without resistance or disease tolerance (Szegedi-20 and Karmin) are not efficient with the organic technology, even if the meteorology conditions are favourable.

The more intense nutrient supply in conventional technology and the plant protection treatments resulted in better morphological parameters, when the water supply was adequate. Without irrigation, the effect of conventional technology on fruit development was moderated, particularly in the dry vintage. The significant precipitation in 2014 and the irrigation on bio-fields in 2015 can be related to the larger morphological characteristics of raw fruits, but this did not result in a higher quantity of dried pericarp. In 2015 with less precipitation, red ripe conventional paprikas had a higher dry matter content due to lack of irrigation, and this resulted in the outstanding yield of dried pericarp and less seed content. In addition to nutrient-supply, the results point to the importance of water supply regulating. In the second year of the experiment, it was clearly demonstrated that more sunshine, higher average temperature and higher number of hot days resulted in faster dry matter accumulation.

Important practical information can be gained from the logistic function describing the accumulation of colour compounds (ASTA, total carotenoids). The conventional cultivation technology has clearly contributed to the development of higher colour content. Especially in the favourable year of 2015, more frequent and intensive nutrient supply increased the differences between conventional and bio colour contents. The study of the dynamics of post-ripening showed that the slower ripening on the fields can be compensated during post-ripening in the less favourable season. Suitable storage conditions and duration should be provided. On the basis of the colour content, the post-ripened paprika fruits were suitable for the production of high quality milled products. The colour content of *Meteorit* paprika is significantly lower than that of other varieties, but it plays an important role in the efficiency of farms due to excellent production indicators.

The evaluation of maturation dynamics with curve fitting on the changes the total carotenoid, red / yellow colour ratios and esterification (non-esterified carotenoids, monoesters and diesters) derivatives groups enables to get further conclusions about synthesis of the individual colour groups. Furthermore, variations due to the varieties, vintage and cultivation methods can be identified.

In the ripening process, α- and β-tocopherol showed no antioxidant activity (or had only minimal activity) in the defences against oxidative damages. The intensity of α and β-tocopherol accumulation dynamics depended on varieties, season factors, and cultivation methods. The 2014's vintage (more precipitation, less sunshine, lower average temperature, and less hot days) had a beneficial effect on the dynamics of α-tocopherol synthesis in the break-red and red ripening stages, resulting in higher α-tocopherol content, than in 2015.

The γ-tocopherol content has drastically decreased in the intense ripening phase defined by the pale red -red colour transition, suggesting that it has participated in the protection against oxidative stress. During post-ripening, the γ-tocopherol level was regenerated, while the L-ascorbic acid acts as the primary antioxidant. Bio-paprika samples had higher L-ascorbic acid content than conventional ones, as the synthesis was more intense in previous maturation stages.

The PCA showed changes in the carotenoid and antioxidant profiles, attributed to vintage and cultivation processes. The vintage has caused variations in the carotenoid profile, at each maturity stage there are minor colorants that can be linked to a particular vintage. The results suggest that there is a relation between the composition of the carotenoid colour profile and the vintage (meteorological) effects. For accurate exploration, a comprehensive study of several years would be needed. It can be concluded that there are no unique carotenoid colorants that distinguish the organically and conventionally cultivated paprikas. Based on the cultivation, there was only a quantitative difference in colour compounds.

The colour stability of paprika powders made from organic and conventional fruits was primarily influenced by the variety, and secondly by the cultivation process. The decisive role of the two factors is due to the faster colour degradation (higher pseudo reaction rates) in the products with higher initial ASTA colour value. Nonetheless, the colour value of powders with higher initial ASTA remained above the colour value of powders with lower initial-value in most of the storage time. Cultivation of high-colour paprika varieties is important for processors to produce equal quality products throughout the year.

The accelerated shelf life test developed in present research can be used to estimate the quality changes of spice paprika powders and to evaluate the results of cultivation experiments or other product development work within a short period of time. The advantage of the light-accelerated test is that it also approximates sensory changes to the phenomena that occur during regular storage, which is not met by temperature-accelerated procedures. Adapting to research or product development goals, evaluation of results is possible from several points of view: estimate of the rate constant (daily or monthly colour degradation), shelf life to a certain ASTA value or to a certain ASTA value loss. The test procedure may also be extended to other products containing light sensitive components, but the estimation of the accuracy should be carried out as described in the dissertation. The future task is the further development of the presented tool, in order to become a commonly used "test equipment".

Due to unfavourable meteorological and / or post-harvest effects, paprika stocks with weaker colour stability can also be appeared. Antioxidant extracts of natural origin and paprika seeds oil are able to reduce the accelerated colour degradation in the milled spice paprika. The paprika seeds oil is less effective compared to tocopherol or rosemary extracts. However, the colour loss is delayed with the help of paprika own components, instead of other plant-derived additives. Another important advantage of seed oil is that the antioxidant components are utilized without the seed addition during the milling. Therefore, there is no decrease in the colour content because of the dilution caused by the seeds. The original characteristics of the paprika powders do not change. An additional research task is to explore the mechanism of action of seed oil and to increase efficiency.

PUBLICATIONS CONNECTED TO THE DISSERTATION

1. Article in impact factored journals:

Koncsek, A., Kruppai, L., Helyes, L., Bori, Zs. and Daood, H.G. (2016): Storage Stability of Carotenoids in Paprika from Conventional, Organic and Frost-Damaged Spice Red Peppers as Influenced by Illumination and Antioxidant Supplementation. *Journal of Food Processing and Preservation* 40, 453–462.p., 12/2015; DOI: 10.1111/jfpp.12623, Impact Factor: 0.791

Koncsek, A, Daood, H.G. and Helyes, L. (2016): Kinetic of carotenoid degradation in spice paprika as affected by storage temperature. *Acta Alimentaria* 45 (4), 459–468.p., DOI 10.1556/066.2016.45.4.1. Impact Factor: 0.357

Nagy, Zs., Daood, H.G., Koncsek, A., Molnár, H. and Helyes, L. (2017): The simultaneous determination of capsaicinoids, tocopherols, and carotenoids in pungent pepper powder. *Journal of Liquid Chromatography & Related Technologies*, 40 (4), 199–209.p., DOI: 10.1080/10826076.2017.1297722 Impact Factor: 0.697 (2016)

Koncsek, A., Helyes, L. and Daood, H. (2018): Bioactive compounds of cold pressed spice paprika seeds oils. *Journal of Food Processing and Preservation* 42 (1) e13403. Accepted: 1 June 2017. DOI: 10.1111/jfpp.13403. Impact Factor: 0.791

2 Journals without IF:

2.1. In English:

Koncsek, A., Horvath, H.Zs, Daood, H.G. and Helyes, L. (2016): Colour evolution of Hungarian red spice paprika varieties from conventional and organic farming. *Analecta Review of Faculty of Engineering*, 10 (1), 6-15.p.

2.2. In Hungarian:

Koncsek Arnold, Daood Hussein G., Miklós Nagy Csaba, Helyes Lajos (2015): Konvencionális és ökológiai termesztésből származó fűszerpaprika összehasonlító értékelése. *Kertgazdaság* 47. évf. 3. sz. / 2015

3. Other publications

2.1. Proceeding (in English):

Koncsek, A. and Daood H.G. (2010): Changes carotenoid pigments of antioxidant supplemented spice paprika during storage. (227-230.p.) *In: Proceedings of Pigments in Food, 6th International Congress. Budapest, Hungary 20-24 June, 2010, 376.p.*

2.2. Proceeding (in Hungarian):

Markovics, E., Koncsek, A., Zsikai, A. (2008): A fűszerpaprika gyártás minőségalapú hatékonyságnövelése a szegedi Rubin Kft-nél. (40-48.p.) *In: Molnár, P., Boross, F. (Szerk.): XVI. Élelmiszer minőségellenőrzési tudományos konferencia (Tihany, 2008. ápr. 24-25.), Konferencia kiadvány. Budapest: EOQ MNB, 354 p.*