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NON-DESTRUCTIVE POSTHARVEST QUALITY MONITORING OF DIFFERENT PEAR AND SWEET PEPPER CULTIVARS

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Postharvest quality changes of two pear and five sweet pepper varieties during cold storage (2±1 °C and 10±1 °C, respectively) and shelf-life (22±2 °C and 20±1 °C, respectively) by non-destructive optical methods (laser backscattering imaging, chlorophyll fluorescence analysis, surface colour measurement) and texture analysis methods (acoustic impulse-response technique, impact method) were determined and monitored. The rate of the change of 'Conference' pears' F_v/F_m chlorophyll fluorescence parameter was lower than for 'Bosc kobak', referring to the cultivar characteristic and photosynthetically active chlorophyll content related maturity and colour change. Acoustic and impact stiffness decreased during shelf-life, referring clearly to temperature related textural change. Taking into account the seven different measuring wavelengths (650–1064 nm), laser scattering parameters showed significant and cultivar dependent changes versus time during cold storage and shelf-life. The used non-destructive methods were found to be suitable for objective sweet pepper quality determination. Cold storage combined shelf-life resulted in a relatively longer shelf-life, with a lower intensity and rate of quality decrease in time, based upon mass loss, stiffness, surface colour, and chlorophyll fluorescence changes. 'Gigant', 'Carma', and 'Kárpia' cultivars were found to be favourable, but 'Kais' and 'Kun' hot pepper samples were really sensitive to quality degradation.

Keywords: chlorophyll fluorescence, impact, acoustic, laser backscattering, shelf-life

Commercial value and marketability of fresh horticultural products are determined by their quality, storage, and shelf-life properties. Despite the available advanced postharvest techniques, shelf-life period represents a higher risk of quality loss and lower possible commercial value. Due to the high demand for fresh horticultural products, there is a continuous need for the investigation of postharvest properties. In Hungary, among fruit and vegetables, the two completely different products, pear and sweet pepper, play a dominant role in the market, either as fresh (sweet pepper) or as fresh and medium/long term stored product (pear). Under improper storage and shelf-life conditions, all the available sweet pepper cultivars are susceptible to fast quality decrease with a relatively short shelf-life. Pears also belong to the perishable and sensitive products, suffering negative internal and external changes that affect negatively the storage potential and the possible commercial value. Rapid, objective, and non-destructive quality determination methods, such as acoustic stiffness and impact stiffness measurement (Diezma-Iglesias et al., 2006; Taniwaki et al., 2009), chlorophyll fluorescence analysis (Saquet & Streif, 2002; Kosson, 2003), and the image processing methods (Romano et al., 2008; Baranyai & Zude, 2009), are frequently used in quality determination and characterization of the responses of horticultural crops to different external stressors, to quantify or predict produce quality.

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1. Materials and methods

1.1. Materials

Postharvest quality changes of pear and sweet pepper samples during cold storage and shelf-life were determined during two separate series of examinations.

One hundred and twenty samples each of two pear cultivars (*Pyrus communis* L. cv 'Bosc kobak' and 'Conference') at optimal stage of ripeness were examined. Pear samples were stored under optimal storage conditions (Mitcham et al., 1996) (2±1 °C, relative humidity 65±7%). In four storage periods, 30–30 samples were withdrawn from cooling chamber at two-week intervals and were stored at 22±2 °C (relative humidity of 40±5%) simulating shelf-life for almost two weeks. Postharvest changes were measured by optical (chlorophyll fluorescence measurement, laser scattering method, and ColorLite spectrophotometer used for surface colour measurements) and texture analysis (impact and acoustic) methods. After the initial measurements, the latter ones were carried out at an almost daily basis on 30 pear samples per cultivar, concerning each withdrawal from cold storage and continued during shelf-life.

Fresh sweet pepper samples (with forcing origin) were harvested in the maturity stage ready for fresh consumption, based upon growers' harvesting practices, and were classified as 'extra' class according to EU quality regulation No 543/2011. Totally, 150 pieces of five different pepper cultivars (3 sweet: *Capsicum annuum* L. cv 'Kárpia' (red coloured pods with thick flesh), 'Carma' (pale yellow pods with medium thick flesh), 'Gigant' (bell pepper type, big dark green pods with thick flesh), 2 hot: 'Kais' and 'Kun' (dark and pale green long pods with medium thin flesh)) were studied. For the simulation of the average commercial conditions, the K10 marked samples (15 samples per cultivar) were cold stored slightly above the optimal temperature (Cantwell, 2013) at 10±1 °C (relative humidity 55±5%) for a week, and thereafter withdrawn for shelf-life storage at 20±1 °C without packaging. The K20 marked control samples were stored for the same time period at 20±1 °C. Postharvest changes were determined by the non-destructive acoustic impulse-response method, chlorophyll fluorescence analysis, tristimulus surface colour measurement, calculation of average mass loss, and by the evaluation of visible changes and defects. Measurements were carried out every second or third day during shelf-life.

1.2. Measuring methods

Chlorophyll fluorescence measurements were carried out using a PAM WinControl-3 controlled MONI-PAM multi-channel chlorophyll fluorometer (Heinz Walz GmbH, Germany) to determine the change in photosynthetic activity (closely related to the tissue's photosynthetically active chlorophyll content). Minimum and maximum chlorophyll fluorescence kinetics (F_0, F_m) were measured. Variable fluorescence ($F_v=F_m-F_o$) and maximum photochemical efficiency (F_v/F_m) were calculated. Measurements were carried out at the two directly opposite sides of each pear and sweet pepper sample.

A purpose built and dark box located laser backscattering imaging system was used as it was published earlier by Dénes and co-workers (2012). The system was equipped with a Photonfocus AG (Switzerland) MV1-D1312CMOS IP camera and seven solid-state laser modules emitting at seven (532–1064 nm) spectral bands. The incident point surrounding surface area got illuminated by diffuse reflectance by the fruit tissue entering the laser beam. This illuminated area was scanned and intensity values were calculated with radial averaging

relative to the incident point. Threshold of the 50% intensity level was used to segment illuminated area and background. From logarithm intensity, profiles slope (S) and full width at half maximum (FWHM) were calculated. The measurement points on the pears were the same as in case of the chlorophyll fluorescence method.

ColorLite sph850 spectrophotometer (ColorLite GmbH, Germany) was used to scan the surface reflected spectra from 400 to 700 nm with 10 nm steps recording the XYZ, L*a*b*, L*uv and xy surface colour parameters. Three repetitions were carried out per sample point located on both sides of the equatorial part of the pears (same points as of the chlorophyll fluorescence analysis).

CIE1976 L*, a*, and b* absolute surface colour coordinates were measured at the same points of chlorophyll fluorescence analysis in case of pepper using a Minolta CR-200 compact tristimulus colour analyser (Konica Minolta Inc., Japan).

For texture measurements, acoustic impulse-response technique and impact method were used as it was published by FELFÖLDI (1996) and FELFÖLDI and IGNÁT (1999), respectively. The characteristic acoustic frequency (obtained by a gentle wooden stick hit on the top of the pepper or on the equatorial part of the pear sample) and the sample mass were used to calculate the acoustic stiffness coefficient (S) of the pear and sweet pepper samples.

$$S_{pear} = f^2 \cdot m^{2/3} \times 10^{-6} \, (Hz^2 \, g^{2/3}) \quad (1)$$

$$S_{pepper} = f^2 \cdot m \times 10^{-6} \, (N \, mm^{-1}) \quad (2)$$

where f is the characteristic (peak) frequency of the sample (Hz) and m is sample mass (g).

The sample's firmness is characterised by the impact stiffness coefficient (D) calculated upon the voltage signal of the impact hammer's accelerometer recorded and analysed by a dynamic signal analyser.

$$D = 1/\Delta T^2 \, (ms^{-2}) \quad (3)$$

where ΔT is the time difference (ms) between initial and maximum points of the recorded time-voltage signal curve. Average impact stiffness was calculated by the data of the measured four points on the equator of each pear sample.

For data conversion MS-Excel and for statistical analysis SPSS ver.14 were used at 95% significance level (ANOVA). The open source software of R (ver. 2.12.1, R Foundation for Statistical Computing, Austria) was used to perform image processing and statistical analysis (ANOVA), and to produce summary reports and charts in case of the laser scattering data analysis.

2. Results and discussion

2.1. Results of the postharvest changes of pear samples

Due to the very similar behaviour and quality characteristics' change of the two pear cultivars, only the results of the 'Bosc kobak' cultivar are presented in the figures.

In case of both cultivars no significant difference was found regarding the measured (F_0, F_m, data not shown) and calculated (F_v/F_m) initial chlorophyll fluorescence parameters, but all of them showed significant decrease during storage (Fig. 1A). The rate of the change of the maximum photochemical efficiency (F_v/F_m) was lower in case of the 'Conference' cultivar.

Fluorescence changes clearly represent the cultivar characteristic and photosynthetically active chlorophyll content related maturity and colour change, either during cold storage or during shelf-life, but at different rates.

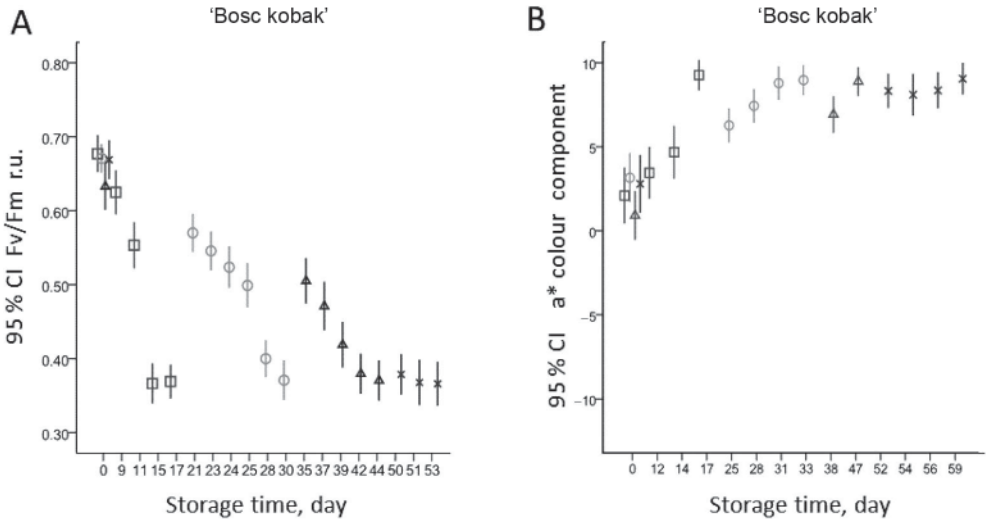

Fig. 1. Change of the F_v/F_m chlorophyll fluorescence characteristic (A) and the a* colour component (B) of the 'Bosc kobak' pear samples vs. storage time. Storage period: □: 1st; ○: 2nd; △: 3rd and ×: 4th.

Hue° and L*a*b* surface colour parameters significantly showed different rates of colour change during the cold and shelf storage period. Figure 1B shows the a* colour component's change. The initial colour of the two pear cultivars was found to be significantly different (dark green 'Conference' and yellowish green 'Bosc kobak' samples).

The a* and Hue° values of both cultivars (Hue° data are not shown) reflected clearly the change from green to yellow colour, representing the effect of storage temperature on ripening related surface colour change, as the samples' colour changed slowly at low temperature compared to the really fast change at the higher room temperature during shelf-life.

Impact stiffness coefficient decreased drastically during shelf-life from the initial 0.2 ms^{-2} to 0.05 ms^{-2} and 0.14 ms^{-2} to 0.05-0.06 ms^{-2} in case of 'Bosc kobak' (Fig. 2A) and 'Conference', respectively. It clearly represents the effect of the storage temperature on texture changes. In case of 'Bosc kobak' cultivar, the acoustic stiffness' monotonous change can be observed (Fig 2B) during the entire storage period. In case of 'Conference', after the initial decrease, the change of the acoustic stiffness coefficient was not significant (data not shown).

Considering the surface colour change related chlorophyll decrease, the FWHM value of the samples obtained by 650 nm laser increased during ripening. In Figure 3, the chlorophyll content decreased slowly at low temperature (the first measured value point of the storage period represents cold storage) and faster at room temperature. The 'Conference' and 'Bosc kobak' cultivars behaved clearly differently, concerning the range of the slope (–1.9 to –1.2 and –1.2 to –0.5, respectively, data not shown) and FWHM (19 to 27 and 30 to 46, respectively) values. Significant differences were found between the initial data and the withdrawals' data in case of the Slope and FWHM values.

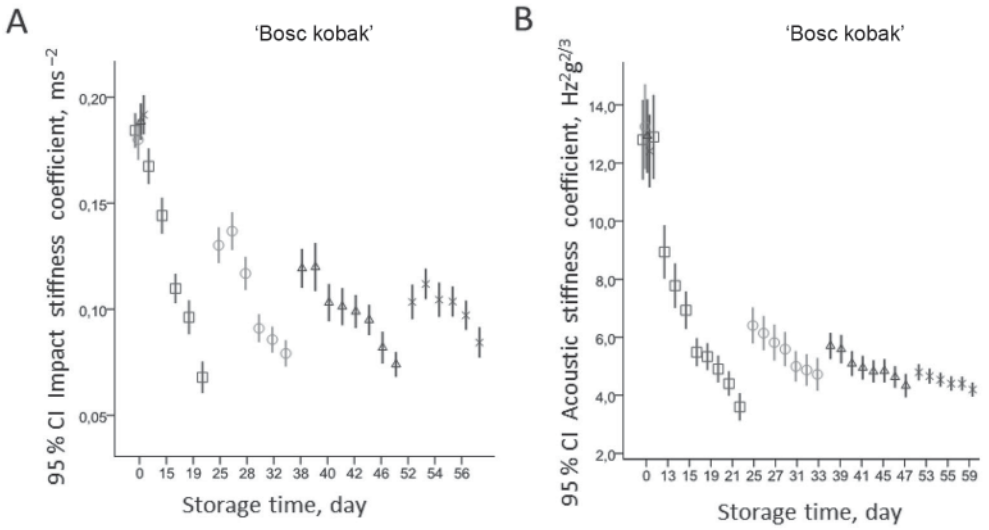

Fig. 2. The changes of the impact (A) and the acoustic stiffness (B) coefficient of the 'Bosc kobak' pear samples vs. storage time. Storage period: □: 1st; ○: 2nd; △: 3rd and ×: 4th

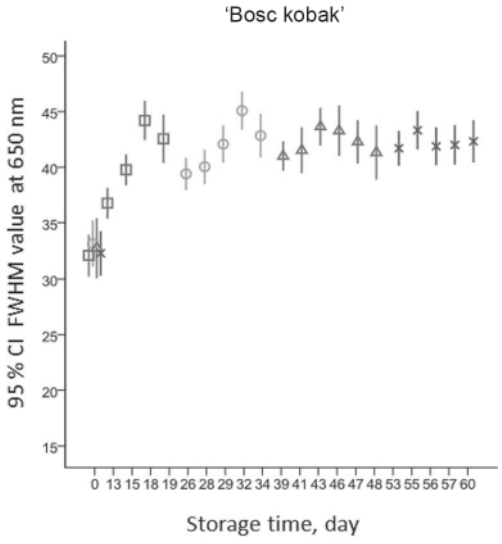

Fig. 3. Change of FWHM backscattering imaging characteristic of 'Bosc kobak' pear samples at 650 nm laser light sources vs. storage time. Storage period: □:1st; ○: 2nd; △: 3rd and ×: 4th

2.2. Results of the postharvest changes of pepper samples

In contrast to the only minor negative changes of the samples stored at +10 °C (K10) for a week, the disadvantageous effect of shelf storage became clearly visible after a few days as cultivar dependent surface colouration ('Gigant', 'Kais' and 'Kun'), wilting, shrinkage, and

softening ('Kais' and 'Kun'). After withdrawal of the good overall quality featured samples (K10) from 10 °C, they also suffered unwanted colour, mass, and texture changes during shelf-life as the K20 samples, resulting in an unacceptable quality at the end of the 17th day.

The mass loss of the samples during storage at 10 °C – independently from cultivar – was under 2% due to the positive effects of low temperature on keeping quality, but after withdrawal to shelf-life, mass loss increased rapidly. Hot cultivars ('Kais', 'Kun') suffered the highest mass loss during shelf-life and entire period, resulting in softening, wilting, and finally a not acceptable overall quality, in contrast to the advantageous results of the sweet 'Carma', 'Kárpia', and 'Gigant' cultivars, which were found to be the best concerning shelf-life. Average mass loss of the K10 marked samples (cold and shelf stored ones) during the 14 days of combined storage was only a little more than the K20 marked samples during the one week of shelf storage.

The textural changes determined as acoustic stiffness coefficient change, clearly proved the results of the mass loss changes. Figure 4 shows the clear effect of cold and shelf storage on stiffness, as only minor textural decrease was measured in case of all cultivars at 10 °C. At 20 °C, stored samples suffered rapid and significant stiffness decrease during the first 2–3 days, resulting in the softening phenomena. Compared to this, the observed acoustic stiffness decrease during the first 2–3 days after withdrawal to shelf-life was found to be less severe and intensive in time, except of 'Kárpia' cultivar, but all samples suffered significant decrease in stiffness and in overall quality.

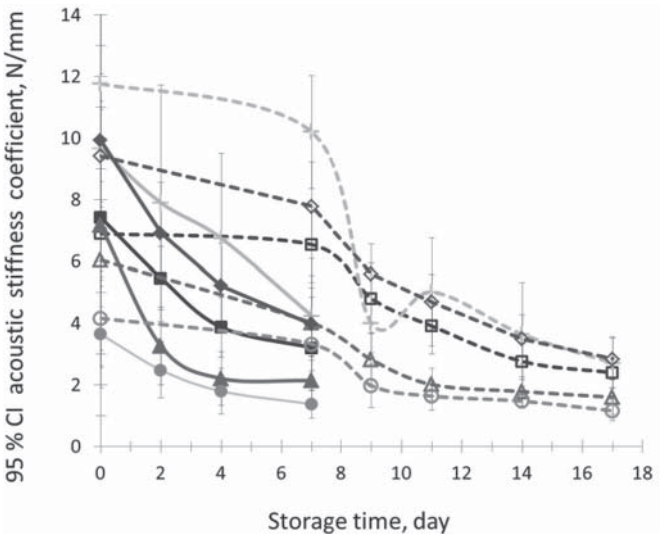

Fig. 4. Acoustic stiffness coefficient change of sweet pepper cultivars vs. storage time
---□---: Carma K10; —■—: Carma K20; ---△---: Kais K10; —▲— : Kais K20; ---○---: Kun K10; —●—: Kun K20; ---x---: Kárpia K10; —x—: Kárpia K20; ---◊---: Gigant K10; —♦—: Gigant K20

Chlorophyll fluorescence measurements also proved the earlier statements. No significant difference was found in case of the measured (F_0, F_m not shown) and calculated (F_v/F_m) initial parameters at the beginning of the experiment, except for the mature red 'Kárpia', but all parameters showed cultivar characteristic decrease during shelf storage

(Fig. 5A) as the inhomogeneous maturation took place. The measured fluorescence changes (decrease in F_m and F_v/F_m) clearly represented in case of the green varieties ('Kun' 'Kais', 'Gigant', and 'Carma') the temperature dependent, cultivar characteristic, and photosynthetically active chlorophyll content related maturity and colour change, either during cold storage or shelf-life at simulated retail conditions, but at different rates. The advantageous effect of lower temperature is obvious, taking into consideration the change of the fluorescence parameters (F_0, F_m and F_v/F_m), as the fluorescence changes are less intensive in time in case of cold and shelf-life combined storage compared to the normal storage results at 20 °C.

In coincidence with Zsom and co-workers (2010), the rate of the photosynthetically active chlorophyll content related change of F_v/F_m was low in case of the red 'Kárpia', but proved the measureable presence of photosynthetically active chlorophyll content even in the case of mature red stage of ripeness.

In case of the surface colour measurement, the postcolouration was clearly visible concerning the K20 marked samples after 5 days of shelf storage, except of the almost mature red coloured 'Kárpia' samples (Fig. 5B). In case of the 'Carma' and 'Kárpia' samples stored at 10 °C for one week (K10), no significant colour change was observed in contrast to a minor change of mature green cultivars ('Kais', 'Kun', and the blocky type 'Gigant'). Except of the 'Gigant', the L* (data not shown) colour parameter showed no significant change during postmaturation. Except of the 'Kárpia' samples, concerning the a* parameter's change of the K10 and K20 samples stored at 20 °C, cultivar and temperature dependent intensity characterized continuous a* increase was measured referring to an inhomogeneous maturation pattern with great standard deviation.

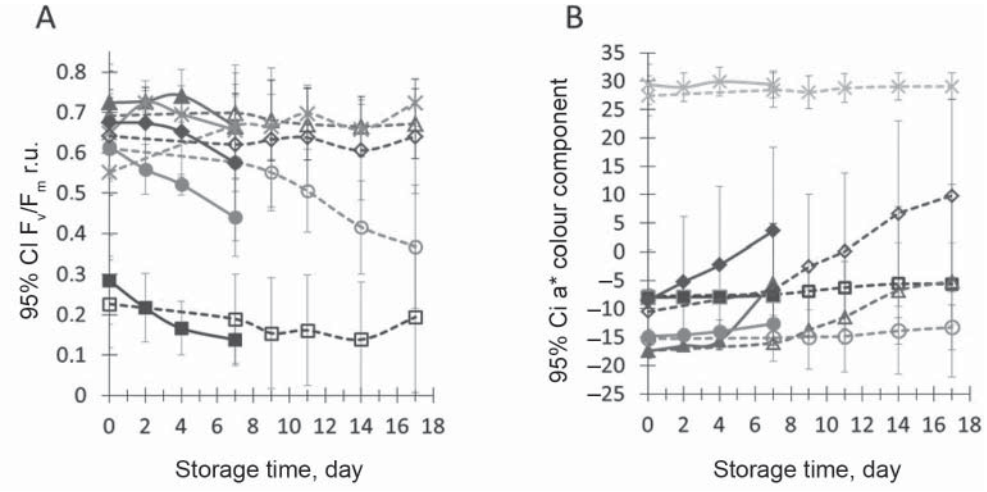

Fig. 5. The change of F_v/F_m photosynthetic activity (A) and the CIE Lab a* colour coordinate (B) of sweet pepper cultivars vs. storage time. ---□--- : Carma K10; —■—: Carma K20; ---Δ---: Kais K10; —▲—: Kais K20; ---○---: Kun K10; —●—: Kun K20; ---x---: Kárpia K10; —x—: Kárpia K20; ---◊---: Gigant K10; —♦—: Gigant K20

3. Conclusions

According to the results presented above, all the applied non-destructive measuring methods were found to be suitable for the detection and monitoring of postharvest quality changes of pear and sweet pepper cultivars during cold storage and subsequent shelf-life.

Concerning the pear results, acoustic and impact stiffness coefficients, chlorophyll fluorescence characteristics, laser scattering, and surface colour parameters showed significant change during the postharvest cold storage and shelf-life periods, and they are closely related to storage temperature. The F_v/F_m chlorophyll fluorescence parameter's change clearly referred to the cultivar dependent and photosynthetically active chlorophyll content related maturity and colour change at both conditions. According to the laser backscattering results, setting laser wavelengths to 650 nm can be suitable to detect maturity related chlorophyll content decrease.

According to the sweet pepper results and in coincidence with Zsom and co-workers (2010) findings, all the used non-destructive methods were found to be suitable for the determination of postharvest quality changes of the sweet pepper cultivars during cold storage and shelf-life. Taking into consideration the measured quality parameters, the 'Kais' and 'Kun' hot cultivars were found to be the less shelf-life suitable ones in contrast to 'Gigant', 'Carma' and 'Kárpia' cultivars. Due to the positive effect of low (not chilling) temperature, combined cold and shelf storage caused less intensive overall quality decrease during shelf life. As the cultivar dependent results of the colour measurement and chlorophyll fluorescence analysis providing only local, but not overall information, the inhomogeneous pepper maturation with increasing and overlapping standard deviation suggests the need for higher number of sampling points, subsequent sampling at the significant colour changes, and/or the use of machine vision and chlorophyll fluorescence imaging systems in order to determine colour and photosynthetic activity change during shelf-life maturation.

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