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STUDY OF WATER TRANSPIRATION FEATURES OF SWEET PEPPER USING A THERMAL IMAGING SYSTEM AND NON-DESTRUCTIVE QUALITY MONITORING DURING POST-HARVEST STORAGE

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Sweet pepper is susceptible to relatively fast quality changes and its quality is influenced strongly by water or mass losses mainly due to transpiration processes during post-harvest. The aim of this study was the investigation of different storage conditions' effect on quality maintenance of pepper using surface thermal imaging, measurement of overall static stiffness and low-mass impact stiffness as non-destructive methods. Post-harvest keeping quality of pepper samples increased and unfavourable quality degradation was prevented under low, non-chilling temperatures together with the use of LDPE-packaging film resulted in high quality and fresh appearance after more than two weeks long storage period.

Keywords: *elasticity, impact stiffness, pepper, post-harvest, quality, transpiration rate*

Introduction

There is an increasing demand from the consumers' side in the market for products with excellent quality and extended shelf life. So the preservation of product quality or the prolongation of the keeping quality became more and more important together with the optimisation of storage conditions. Improper post-harvest storage conditions rapidly lead to wilting and softening of fruits and vegetables, largely reducing the overall quality of freshly harvested horticultural products and shorten their shelf life [2, 4].

The thermal behaviour of foods strongly depends on their composition (i.e. carbohydrates, lipids, proteins, water etc.) [9]. Under improper conditions the high initial moisture content of horticultural products rapidly declines after harvest due to transpiration processes at the product surface. Post-harvest water or mass losses in fruits and vegetables depend on produce properties at the date of harvest and on post-harvest environmental conditions [7]. Transpirational water losses have great influence on post-harvest quality and keeping quality of fruits and vegetables. Very often, local surface temperature differences can be found between individual plant parts, e.g. between fruit body and stalk, representing different water transpiration features. Different rates of water evaporation, as indicated by heat and mass transfer from the product surface, lead to a differential decrease in surface temperature [6]. These temperature differences can be easily measured by thermal imaging systems [7].

High quality sweet pepper fruits are characterized by ripeness, intactness, high sugar and vitamin contents, adequate fruit firmness and colour. Only objective and non-destructive methods guarantee a continuous and effective quality monitoring from the field to the consumer [11]. Consumer acceptance and purchase decisions of sweet pepper are strongly influenced by the visible and sensible signs of reduced product freshness and overall quality.

Aims

The objective of this study was to investigate the effects of different post-harvest storage conditions (storage temperatures of 10 and 20°C, with and without sealing in LDPE-bags) on the quality maintenance of two sweet pepper varieties, which covering a wide range of consumer preferences, using non-destructive methods such as surface thermal imaging, measurement of overall static stiffness and low-mass impact stiffness.

Materials

Freshly and carefully harvested greenhouse-grown sweet pepper fruits (*Capsicum annuum* L.) of the ma-

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Table 1 Signs and abbreviations used for distinguishing different pepper varieties and treatments

Variety	Abbreviation	Temperature/°C	Packing type	Symbols
Hó F1	HNA	10	unpacked	△
	HPA		packed	▲
	HNB	20	unpacked	◇
	HPB		packed	◆
Kárpia F1	KNA	10	unpacked	○
	KPA		packed	●
	KNB	20	unpacked	□
	KPB		packed	■

ture-red variety Kárpia (fully ripened) and the mature-white Hó in uniform size and maturity were directly obtained from a local grower. Pepper samples were stored at 10°C and at room temperature (20°C) with and without sealing in commercially available LDPE-bags (4 fruits per bag) in order to simulate typical and realistic storage conditions during the entire post-harvest chain that differentially effect fruit quality. 60 samples of each variety and treatment (total sample size: 480) were used in the experiments. Samples were taken out of storage every third (10°C) and second day (20°C) and used for the evaluation of quality changes. Table 1 shows the signs and abbreviations used for distinguishing different pepper varieties and treatments during the experiments.

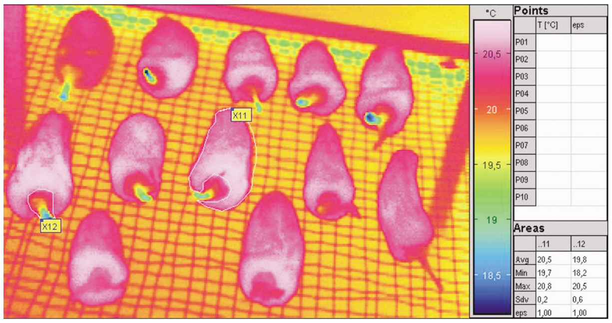
Methods

The following transpiration features of the pepper fruits (placed on a grid) under unrestricted natural convection were determined during storage:

- area-related transpiration rate E (mg cm^{-2} h^{-1}), as the water loss or mass of moisture transpired per unit fruit surface area and time [3, 6],
- total transpiration resistance r_{total} (s cm^{-1}), as the sum of the boundary layer resistance and tissue resistance [10],
- and tissue resistance r_{tissue} (s cm^{-1}, characterising the water status of the produce) [7].

The post-harvest wilting phenomenon (total mass or water loss) can be described by the transpiration resistance (characterising the water status of the produce).

Every five minutes for a one-hour period surface thermal images (Fig. 1) showing the temperature distribution at the pepper surface, were taken by a liquid N_2-cooled thermal imaging camera system (Varioscan 2011, JenOptik, Jena, Germany, Fig. 2) connected to personal computer. Average surface temperatures of fruit and stalk were evaluated by IRBIS (ver. 1.0) commercial imaging analysis software (InfraTec GmbH, Dresden, Germany). Temperature and relative humidity of the surrounding air were recorded with an ALMEMO3 data logger (Ahlborn, Holzkirchen, Germany). The difference in fruit mass over the measuring interval was determined using a BP 210S electronic balance (Sartorius AG, Göttingen, Germany). Water transpiration features of fruit bodies and stalks were evaluated individually according to the calculation method by co-author M. Linke and the formulation summarized by Inoue *et al.* [5] using the measured features of the air (temperature, relative humidity, etc.) and the respective average surface temperature.



Points

	T [°C]	eps
P01		
P02		
P03		
P04		
P05		
P06		
P07		
P08		
P09		
P10		

Areas

	..11	..12
Avg	20,5	19,8
Min	19,7	18,2
Max	20,8	20,5
Sdv	0,2	0,6
eps	1,00	1,00

Fig. 1 Surface thermal image of pepper samples shown by IRBIS commercial imaging analysis software

Fig. 2 Picture of the surface thermal imaging system (Varioscan 2011)

Overall quasi-static fruit stiffness as indicated by Young's modulus or elasticity (N mm^{-1}) was determined by compressive force-deformation analysis from the measured deformation at a given force of 2N using a SMS TA-XT2i texture analyser (Stable Micro Systems Ltd., Godalming, UK) fitted with an 11 mm standard Magness-Taylor probe. Measured data were stored and analysed using the SMS Texture Expert program. Tests were carried out in the geometrical middle on two opposite sides of each fruit in initial state and after each removal from storage.

Dynamic low mass impact stiffness [1, 8] was measured using an impact PCB (PCB, Depew, NY, USA) hammer (fitted with a piezoelectric accelerometer), modally tuned with a steel impact mass connected to a HP 35670A dynamic signal analyser for impulse recording by gently hitting the samples at the given places. The impact stiffness coefficient d $[1/(\Delta t)^2, \mathrm{s}^{-2}]$, which closely indicates the sample's surface stiffness, was calculated from the time between the onset of the impulse and the maximum force. The dynamic impact stiffness coefficient is used in order to characterize the sample's surface stiffness. Tests were carried out in the geometrical middle on two opposite sides of each fruit in initial state and after each removal from storage.

Relative mass loss (RML; % of initial fruit mass) of each fruit was calculated from the changes in fruit mass measured to 0.01 g with an electronic balance (Sartorius AG, Göttingen, Germany).

Results

Water transpiration features of pepper samples

Fruit transpiration generally tended to be higher in samples of the variety Kárpia (Fig. 3). This was due to their significantly lower tissue resistance to water vapour transfer (Fig. 5). Under both temperature conditions, fruits' transpiration reversible increased only in non-packed Kárpia samples during the initial storage period. In fruits of the other treatments transpirational water losses were low and constant throughout the entire storage time. Despite a lower temperature diminution of the fruit bodies (c.f. Fig. 1) the calculated transpiration rates of the entire fruits were almost four times that of the stalks (Fig. 4). Evaluation of the surface temperature difference between the fruit and the stalk suggested that the drying out of the stalks (visible signs of wilting on the fruit surface were visible too) especially in case of samples stored without packaging at higher temperature. So the water vapour flow from inside the berry was more and more interrupted, represented by a decrease in transpiration rate of the stalk and an increase in tissue resistance of the pepper fruit, independently of the variety.

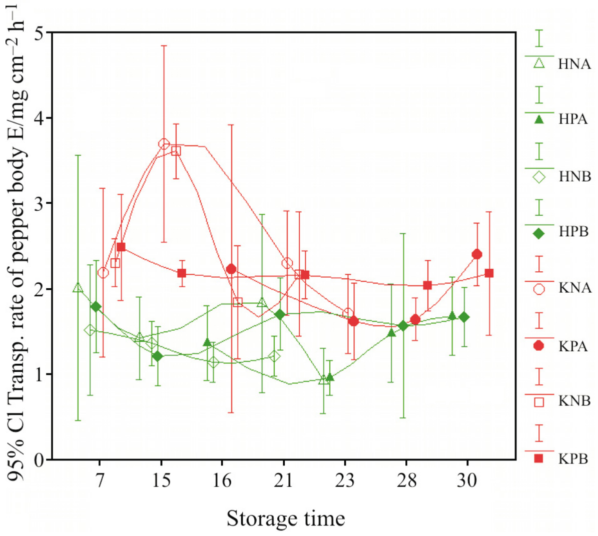


Fig. 3 Transpiration rate (mg cm^{-2} h^{-1}) of LDPE-packed and non-packed Hó and Kárpia pepper bodies during post-harvest storage at 10 and 20°C

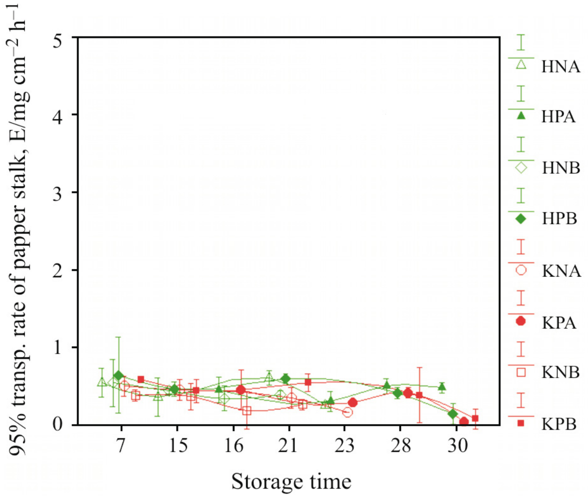


Fig. 4 Transpiration rate (mg cm^{-2} h^{-1}) of LDPE-packed and non-packed Hó and Kárpia pepper stalks during post-harvest storage at 10 and 20°C

According to the higher surface temperature differences between the fruit and the stalk in LDPE-packed samples stored at 10°C, the transpiration rates of stalks were higher because of the less wilted stalk's surface and the lower relative mass loss. This may suggest higher capability of transpiration due to the better physiological condition of the sample.

Relative mass loss

RML, calculated as the actual percentage of initial fruit mass, showed a clear and significant difference between LDPE-packed and non-packed samples, in-

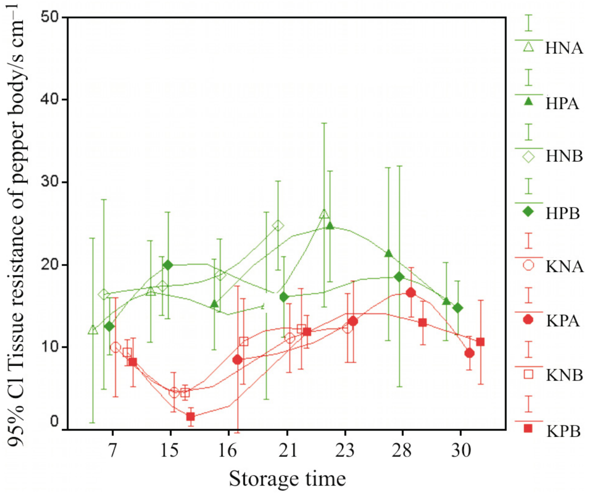


Fig. 5 Tissue resistance (s cm^{-1}) of LDPE-packed and non-packed Hó and Kárpia pepper samples during post-harvest storage at 10 and 20°C

dependent of storage temperature and variety. The significant difference in RLM observed between the non-packed samples at both temperatures after the first week of storage (Fig. 6), highlighted the dependence of mass losses on water vapour pressure deficit of the surrounding air. This strong dependence may indicate that these mass losses were nearly exclusively due to transpirational water losses. In case of LDPE-packed samples a significant difference in RLM was observed between the two temperature treatments. This may result from the proper microclimate (high relative humidity) inside the packages preventing excessive mass losses (Fig. 6).

Non-destructive texture measurements

Overall quasi-static fruit stiffness (Fig. 7) and dynamic impact stiffness (Fig. 8) showed the same changes during storage. Within the first few days, fruit body stiffness decreased and, hence, elasticity increased mainly in case of non-packed fruits at both temperatures. This indicates the rapid changes in quality that were also shown by the rapid increase in RML. Independent of storage temperature stiffness has reached a low and constant level after the first week of storage in non-packed fruits. In contrast, changes in the elastic properties were slow and almost negligible in LDPE-packed samples (Figs 7 and 8). Furthermore, in either variety no significant storage temperature effects on elastic property differences were found in case of LDPE-packed samples, indicating that packing effectively prevented loss of fruit stiffness and hence sensational firmness.

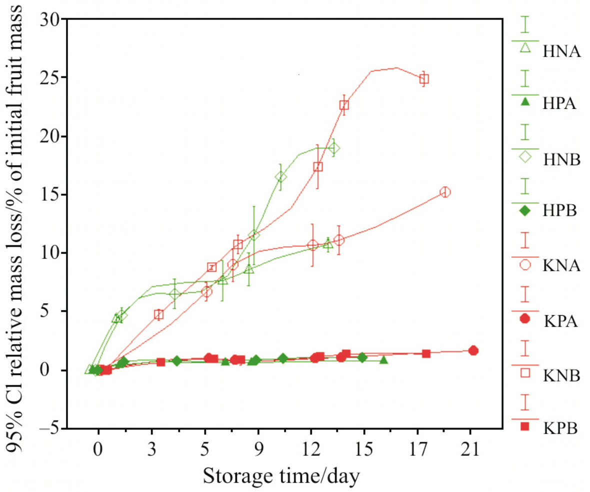


Fig. 6 Relative mass loss of LDPE-packed and non-packed Hó and Kárpia pepper samples during post-harvest storage at 10 and 20°C

The presented results clearly indicate that the impact stiffness very closely reflected the results of

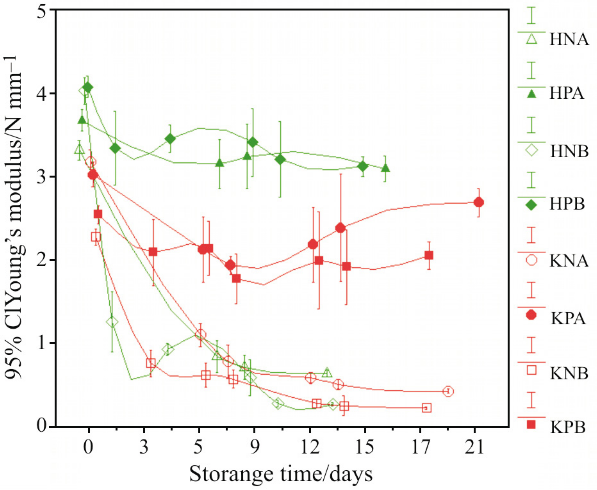


Fig. 7 Elasticity (Young's modulus, N mm^{-1}) of LDPE-packed and non-packed Hó and Kárpia pepper samples during post-harvest storage at 10 and 20°C

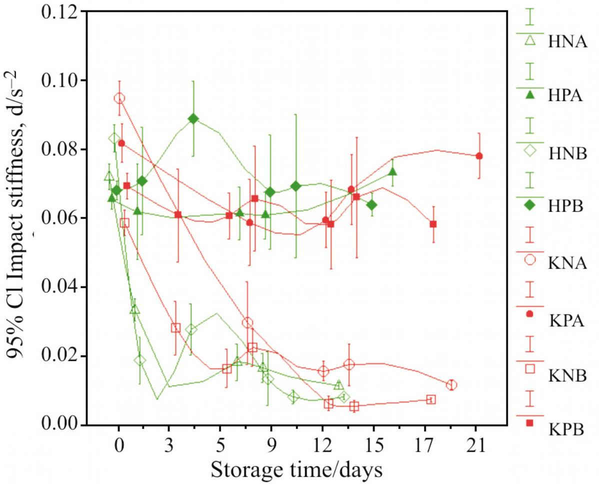


Fig. 8 Impact stiffness (d, 1 s^{-2}) of LDPE-packed and non-packed Hó and Kárpia pepper samples during post-harvest storage at 10 and 20°C

the quasi-static force-deformation technique. The high linear correlation (r^2>0.9) between both stiffness parameters point out that both methods reliably represent the same textural pepper quality aspects.

In case of non-packed samples at both temperatures rapid and significant decrease was measured during the first days of storage comparing to the slow and almost negligible change observed in case of packed samples (Fig. 8). Impact stiffness showed significant difference between packed and unpacked samples from the first few days of storage in case of both varieties, but no significant difference was observed between the packed samples of the two varieties concerning storage temperature.

Obviously, packing very effectively prevented excessive mass loss, which, in turn, prevented loss of produce stiffness. Both quasi-static fruit stiffness and dynamic impact stiffness are in close and sensitive relation to produce water status as roughly indicated by relative water loss. However, the presented results stresses that only the initially 5% of the total rapid mass change are relevant. Further changes in tissue elastic properties are very only minor and largely independent of transpirational water losses.

Conclusions

Transpiration features showed pronounced differences between transpiration rates of fruit body and stalk, as evaluated from the surface temperature difference between the fruit and the stalk. Transpiration rates and tissue resistances of fruits of the different treatments were not significantly different in most cases. However, a higher tissue resistance of the Hó samples partially resulted in lower fruit transpiration.

Relative mass loss showed significant differences between non-packed and LDPE-packed samples. In case of non-packed samples the mass loss was mainly due to transpirational water loss, because of the strong RML dependence on water vapour pressure deficit of the surrounding air.

Both non-destructive stiffness determination methods gave relevant information about the change in quality. Both quasi-static and dynamic stiffness were highly and linearly correlated (R^2>0.9) reflecting the same quality changes of pepper samples during storage. Both non-destructive parameters are sensitive and precise indicators of produce water status as represented by relative water loss.

Post-harvest keeping quality of pepper samples increased and unfavourable quality degradation was prevented when fruits were stored under low, non-chilling temperatures. The use of thin commercial LDPE-packaging film resulted in high quality and fresh appearance after more than two weeks of storage.

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