Int. Agrophysics, 1994, 8, 469-473

EVOLUTION OF MATURITY OF PEACHES. NON-DESTRUCTIVE FIRMNESS MEASUREMENT FROM THE ACOUSTIC IMPULSE RESPONSE

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A b s t r a c t. An experiment was set up to monitor the evolution of the maturity, indicated by the weight loss and the firmness, of Sudanell and M. O'Henry peaches. The resonant frequency, measured with the acoustic impulse response technique, was used to determine the fruit firmness non-destructively. The test was evaluated for peaches by comparison with the destructive quasi-static parallel plate compression test.

K e y w o r d s: peaches. acoustic impulse, non-destructive measurement

INTRODUCTION

The consumers demand for quality fruits is increasing in an almost saturated fruit market. This makes it mandatory for growers and distributers to deliver high quality products. Therefore, knowledge of the development or loss of the fruit quality attributes during transportation, storage, handling and delivery to the consumer and knowledge about how the ripening process can be manipulated is of major concern.

Flesh firmness is used as an indicator of fruit texture or maturity. The most objective technique, suggested by the USDA, for measuring this firmness is the Magness-Taylor firmness (with penetrometer). But this method is destructive and this firmness does not consistently correlate with the degree of maturity of peaches [9].

Firmness and maturity of fruits and vegetables are strongly correlated to their frequency response characteristics, which can be measured non-destructively [8]. Finney [7] reports that the whole frequency spectrum of peaches, measured with the random vibration method, moves to lower frequencies as the peach becomes softer. This can be explained by the lower transmissibility of the vibrations through the fruit of the high frequencies as the fruit softens. Instead of excitation of the fruit with a shaker the fruit can be excited with a mechanical impulse. A mathematical development of the theory of vibration of an elastic sphere is given by Chen and De Baerdemaeker [4].

For apples the acoustic impulse response method was proved to be less time consuming and more accurate than the random vibration method [5]. A strong relationship was obtained between predicted elastic modulus and elastic modulus measu-red by an axial compression test on a test specimen from the apple [1].

The objective of the work reported here was to compare the acoustic impulse response method with the compression test for peaches. Using this method, the maturity of peaches of different varieties was monitored non-destructively during cold storage and shelf-life.

MATERIALS AND METHODS

Materials

The peaches came from Lérida (Spain) in September 1992. Two varieties were tested. Peaches of the first variety, Sudanell, have a yellow skin and hard flesh. The flesh is difficult to remove from the pit (cling stone). These peaches were harvested shortly before at the time of delivery. Peaches of the second variety, M. O'Henry, have a red skin and soft and yellow flesh, which is easily removed from the pit (free stone). These peaches were stored for approximately 1 month in the cooperative before transportation to Leuven. Of each variety, 10 peaches had been transported in cool boxes to prevent ripening and 10 peaches were transported unchilled.

Non-destructive firmness measurement

The peaches were excited by striking the peach with a plastic rod on the cheek. The response of the peach to the impulse, which consists of pressure waves coming from the fruit and transmitted through the air, was measured with a MCE101 microphone and sent to a Structural Dynamics Analyzer HP 35665A. This analyzer was configured to perform a Fourier transform on the signal. The resonant frequencies of the fruit could be obtained from the resulting frequency spectrum. The stiffness coefficient can be calculated as $f^2m^{2/3}$, with f being the resonant frequency and m the fruit mass [4].

Destructive firmness measurement

The static modulus of elasticity of the flesh was determined at room temperature with a parallel plate compression test on a Universal Testing Machine. Penetrometer measurements on peaches would give an indication of the shear modulus while elasticity values from parallel plate compression of whole fruits seemed more indicative of overall peach firmness [6]. Small cylindrical peach specimens were taken (10 mm diameter, 10 mm length). Compression speed was 15 mm/min until breakpoint was passed. This breakpoint was identified on a 10 % drop of the force during compression. The elastic modulus was calculated from the slope of the curve deformation versus force. Also the force at yield point and the energy required to reach the maximum force were recorded. The compression test was performed on at least 4 samples taken from both cheeks of each peach.

Experimental design

Upon arrival from Spain, the peaches were numbered, weighed and placed in a chamber with storage conditions of 96 ±1 % RH and 2 °C. Every 3 h there was a defrost cycle of 15 min during which the temperature in this room could briefly reach 6 °C.

The cool transported peaches were kept in the refrigerated chamber for 5 days and then transferred to shelf-life, in a chamber with a relative humidity of 90 ±1 % and a temperature of 18 °C. The weight and the resonant frequency of these peaches were monitored during the cold storage and the shelf-life.

The unchilled transported peaches were used to perform destructive and non-destructive firmness measurements and to compare the results of both measurement techniques.

RESULTS

The effect of variety and storage time on weight loss and resonant frequency was analysed with an analysis of variance [10]. The evolution of the mean weight loss and the mean resonant frequency of both varieties are presented in Fig. 1.

An analysis of correlation was performed on the different parameters obtained by both firmness measurement methods for the two varieties of peaches. The resulting correlation coefficients for Sudanell and M. O'Henry peaches are shown in Table 1, respectively.

DISCUSSION

Evolution of the weight loss and firmness

From the analysis of variance and Fig. 1 could be concluded that the evolution of the weight loss was similar for both varieties (mean weight loss of 0.28 % of the original weight per day at 2 °C and 96 % RH, and

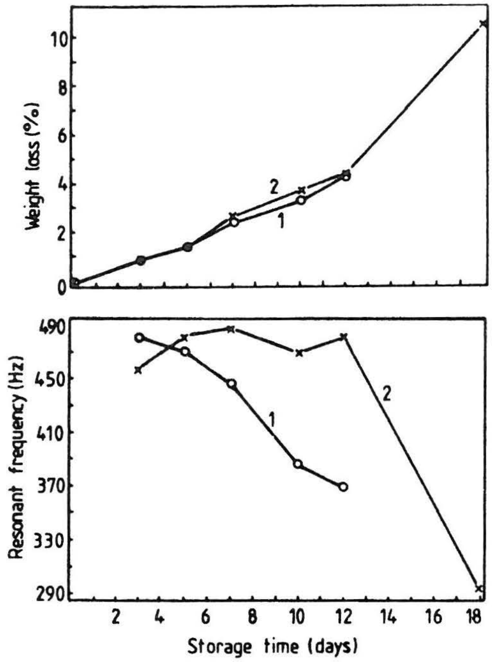

Fig. 1. Evolution of the mean cumulativle weight loss and resomant frequency of Sudanell (1) and M. O'Henry (2) peaches during storage and shelf-life. Storage conditons: day 0-5: 2 °C, 96 % RH; day 5-18: 18 °C, 90 % RH.

mean weight loss of 0.4 % of the original weight per day at 18 °C and 90 % RH).

During the cold storage the weight loss was not significant for M. O'Henry peaches. After transfer to higher temperature, the loss became significant. Sudanell peaches showed a significant weight loss at each measurement.

The evolution of the firmness of the peaches was monitored on the basis of the resonant frequency, determined from the acoustic impulse response.

From the analysis of variance of the interaction time of storage and variety and also from Fig. 1 it could be concluded that the evolution of the resonant frequency was significantly different for the two varieties.

Sudanell peaches became significantly softer as they were removed from the cool to the warm chamber after 5 days. After the 12th day of the experiment, the average decrease in resonant frequency for Sudanell peaches was ±100 Hz.

The firmness of M. O'Henry peaches did not change significantly during that period, until after the 13th day of the experiment. After 18 days, the resonant frequency decreased with ±150 Hz. From the evolution of the resonant frequency of individual peaches was observed that almost 50 % of the M. O'Henry peaches showed an increase in resonant frequency during the first 12 days of the experiment. The other half of the peaches remained equally firm or softened very little. After 18 days all the M. O'Henry peaches had become significantly softer.

One possible explanation for this behaviour could be the different connection of the mesocarp to the pit for the two varieties. Further investigation of the influence of this property is required. Another reason for this different ripenning pattern could be a different storage history (M. O'Henry peaches were stored before transportation, while the Sudanell peaches were harvested shortly before the experiment). There is probably a combination of the effect of a different stage of ripeness and the effect of low temperature history. Brusewitz *et al.* [2] also reported that storage at low temperature retards quality degradation. Immediate cooling of freshly harvested peaches in high relative humidity significantly reduces the weight loss and bruising of ripe peaches. This is indeed what was noticed in this experiment for the firmness, but not for the weight loss. More investigations are needed for a confirmation of these results.

Evaluation of the measurement techniques

From Table 1 can be seen that the correlation between the different parameters are higher and more significant for M. O'Henry than for Sudanell peaches.

These correlations are not so high compared to what Finney [7] measured between the index of firmness $f^2m^{2/3}$, derived nondestructively from a random vibration test,

Table 1. Correlation analysis for Sudanell peaches and M. O'Henry correlation coefficients/significance probability of the correlation under Ho: $\rho=0$

Parameter	Yield point force (N)	Work (J)	Elasticity (MPa)	Resonant freqency (s^{-1})	Stiffness ($g^{2/3}s^{-2}$)
			for Sudanell peaches		
Stiffness ($g^{2/3}s^{-2}$)	0.51220 0.1586	0.52253 0.1490	0.56942 0.1095	0.99199 0.0001	1.00000 0.0
Resonant freqency (s^{-1})	0.46571 0.2064	0.47570 0.1956	0.49747 0.1730	1.00000 0.0	
Elasticity (MPa)	0.86978 0.0023	0.88467 0.0015	1.00000 0.0		
Work (J)	0.98785 0.00021	1.00000 0.0			
Yield point force (N)	1.00000 0.0				
			for M. O'Henry peaches		
Stiffness ($g^{2/3}s^{-2}$)	0.75324 0.0191	0.72347 0.0276	0.59400 0.0917	0.98725 0.0001	1.00000 0.0
Resonant freqency (s^{-1})	0.75012 0.0199	0.74568 0.0211	0.58242 0.0998	1.00000 0.0	
Elasticity (MPa)	0.95663 0.0001	0.87219 0.0022	1.00000 0.0		
Work (J)	0.95150 0.0001	1.00000 0.0			
Yield point force (N)	1.00000 0.0				

and the resistance force, measured destructively with a Magness-Taylor probe. Chen *et al.* [5] measured a correlation coefficient of 0.746 between the stiffness factor $f^2m^{2/3}$ and the static modulus of elasticity for Delbard Jubile apples. The low number of tested peaches (10 for each variety) has to be taken into account.

The size of the compression test samples was very small in order to obtain the statistically required amount of replicates (4 per peach). Enzymatic degradation reactions occur very fast from the moment the specimens are cut and start from all the sides of the cut sample. As the degradation of the intercellular pectin bounds had started before the sample was tested, inevitably, the real firmness value of the flesh can not be determined. Another reference technique should be used, which is a good indicator of peach maturity and overall peach firmness. Error sources in the acoustic impulse response technique are the shape-dependency of the value of the first resonant frequency, the uncontrolled magnitude of the impact force, the fruit temperature and the water potential [3]. An extra error source, when applied to softer fruits, is the difficulty to detect the main resonant peak. The presence of a pit in the fruit probably has an influence on the vibrational pattern.

CONCLUSIONS

The evolution of the weight loss was similar for the two varieties but the evolution of the resonant frequency was significantly different. Sudanell peaches became softer at each measurement, while the firmness of M. O'Henry peaches remained constant until after 13 days of storage at high temperature. The reason for this different ripening behaviour should be further investigated.

The correlation between the destructively measured static modulus of elasticity and the non-destructively determined stiffness coefficient was not very high for the two varieties. A better correlation could be obtained with more samples or using a different reference firmness measurement than parallel plate loading of cylindrical samples.

Also the vibrational pattern of peaches and other stone fruits should be investigated in order to increase the sensitivity of the acoustic impulse response technique for the determination of the firmness of these fruits.

ACKNOWLEDGEMENT

The research was supported by a grant from the EEC-CAMAR Project No. 8001-CT91-0206 (PL900347): Quality of Fruits: Engineering research for improving the quality preservation during pre- and postharvest operations.

REFERENCES

1. **Armstrong P., Zapp H.R., Brown G.K.**: Impulsive excitation of acoustic vibrations in apples for firmness determination. Trans. ASAE, 33(4), 1353-1359, 1990.
2. **Brusewitz G.H., Zhang X., Smith M.W.**: Postharvest cooling effects on the bruising of peaches. ASAE Paper No. 916036, 1991.
3. **Chen H.**: Analysis on the acoustic impulse resonance of apples for nondestructive estimation of fruit quality. Ph.D. Thesis, Fac. Agric. Sci., K.U. Leuven, 1993.
4. **Chen H., De Baerdemaeker J.**: Effect of the apple shape on the reliability of the non-destructive firmness sensing. AGENG Paper 9211-155, 1992.
5. **Chen H., De Baerdemaeker J., Vervaeke F.**: Acoustic impulse response of apples for monitoring texture change after harvest. Proc. ICAE, Beijing, China, 1992.
6. **Delwiche M.J., McDonald T., Bowers S.V.**: Determination of peach firmness by analysis of impact forces. Trans. ASAE, 30(1), 249-254, 1987.
7. **Finney E.E.**: Random vibration techniques for non-destructive evaluation of peach firmness. J. Agric. Eng. Res., 16(1), 81-87, 1971.
8. **Kimmel E., Peleg K., Hinga S.**: Vibration modes of spheroidal fruits. J. Agric. Eng. Res., 52, 201-213, 1992.
9. **Lott R.V.**: The relationship between stage of maturation and degree of quality in apple and peach fruits. Trans. Int. Hort. Soc., 99, 139, 1965.
10. **Sas Institute Inc.** Sas User's Guide: Statistics, North Carolina, 584, 1982.