Thesis book

DYNAMIC METHODS FOR CHARACTERIZATION OF HORTICULTURAL PRODUCTS

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1. INTRODUCTION

During the last decades several methods were developed for the determination of horticultural products' quality. These methods are based on a good correlation between the measured physical properties and the product's certain quality parameters. Therefore, from the measured physical parameter (indirectly) we can draw a conclusion for the quality of the sample. Human beings use their senses such as sight, touch and smell to make an opinion about a vegetable or about a fruit. First we look at it, and if it has the right color, shape, size and it is free from decease and decay, we investigate its structure. After touching it we try to get information about its ripeness and shelf-life. Next we smell the fruit or the vegetable and try to make a conclusion about its internal parameters (for example: hotness, sweetness, tastiness). The final decision about the product is made upon the information collected by all of our senses. However, the measuring methods/equipments designed for the characterization of the quality of horticultural products are not truly able to be as sufficient as human sensing, but in the research area and in the commerce the instrumental analysis is often preferred to sensory analysis. By this way the subjectivity can be eliminated and objective information can be obtained about the product. Additionally these techniques can offer a "common language" giving information for the research, the industry, and for the commerce both for the growers/producers and for consumers.

One of the most important quality parameter of horticultural products is the firmness. Concerning firmness measurement of the product, the destructive reference methods come to our mind. Nowadays, the research activity prefers non-destructive methods, because they have several advantages compared to the „traditional" destructive methods. These advantages are as follows:

- non-destructive measurements are not invasive, so the sample can be stored further,
- from the research point of view the non-destructive methods play great importance, because the changes during storage can be followed exactly, we are able to examine the same product every measuring day and we get more precise information about the physiological and textural changes during storage,
- the sample can be sold or can be manufactured after the test, so the non-destructive methods are financially more advantageous than the destructive ones,
- because of the non time-consuming test, these methods are suitable for on-line sorting and great amount of product can be examined in a short time,
- it is easy to settle and use, it can be portable offering measurements at product delivery or it can be used even in the field,
- there is no need for sample preparation, so it can save time and money.

2. OBJECTIVES

The main objectives of my thesis work were as follows:

- Investigation of the suitability of acoustic stiffness measuring method for non-spherical products, development of suitable measuring setup configuration for the detection of appropriate acoustic response.
- Examination of the measuring parameters' (impact speed, temperature, shape and material of the impactor's head) effect on the impact response and on its parameters.
- Examination of the carrot's stiffness changes caused by heat treatment using the acoustic and impact stiffness measurements, comparison of the so obtained results with the data obtained by the "traditional" non-destructive penetrometric stiffness measurement.
- Determination of the suitability of acoustic stiffness method for in-vivo tomato stiffness measurement. Application of acoustic stiffness method for the evaluation of stiffness decrease during tomato berry development and ripening.

3. MATERIALS AND METHODS

3.1 Improving of the applicability of acoustic method

Ansys Finite Element Modeling program (modal analysis) was used for the confirmation of my preliminary results from another point of view. The popular Hó variety served as a base for the generation of the Finite Element geometry.

Danubia, Hó, HRF, Kamléleon and Kárpia varieties were used to the storage experiments. The 15 pieces of paprika per variety were harvested in a ripening stage ready for consumption. In the first test for the investigation of the quick quality changes pepper samples were stored at room temperature without packaging for almost two weeks. In the second test samples were stored at 18°C for two weeks. During the measurement periods the samples' stiffness changes and the weight loss were determined in every 2^{nd}-3^{rd} days. Every measurement was carried out at the same paprika exactly in the same position.

In the acoustic stiffness measurement paprika samples were excited at two different places:

- at the top and
- at the shoulder part.

In contrast to this, in the impact stiffness measurement, the stiffness of the paprika was evaluated by tapping the paprika

- on its shoulder and
- on its middle part on the side.

3.2 Problems with the dynamic texture measurements – methodological analysis

Personal computer controlled automatic impact stiffness measuring system - developed at Physics and Control Department, Faculty of Food Science, Corvinus University of Budapest - was used for the measurements. In this system, the hitting force of the impact hammer was adjusted by an electromagnet providing almost the same hitting speed of the impact or. The system was equipped with an angle adjustable, turnable sample holder (turntable) and the rotation was PC controlled. Due to this controlled rotation exactly the same position of the sample could be examined. During the measurement after each hit the sample holder rotated exactly 6 ° providing 60 different positions' measurement per sample.

Different fruits and vegetables were used for the methodological examinations. In order to eliminate the natural biological variability model samples were also examined.
The reproducibility tests were carried out on different model materials (ping-pong ball, tennis ball, rubber ball, solid foam ball and silicon rubber block) and on different biological materials (apple, nectarine, paprika, tomato, onion and pear).

Surface stiffness changes on the equator of the samples were examined in case of the following biological materials: apple, nectarine, paprika, tomato, onion and pear.

In order to determine the textural changes caused by different shaped impactor head nectarines and pears were measured.

Apples, tomatoes and nectarines were measured using an 8 mm in diameter cylinder type rubber impactor head with spherical end.

The temperature effect on the impact stiffness coefficient was investigated in case of apple, paprika and tomato.

At least 3 repetitions were carried out in case of every fruit and vegetable type.

3.3 Stiffness changes of carrot measured by acoustic and impact methods

The commercially available carrot samples were microwave heat treated. The aim of the heat treatment was to induce fast texture change. Microwave irradiation of intact carrot samples was used for heat treatment during the experiments. Two different power levels were used for this purpose: 500W and 900W. The treatment duration was 30s, 60s, 90s, 120s, 150s, 180s, 210s and 240s in case of 500W power and 30s, 60s, 90s, 120s, and 150s in case of 900W power. All group contained 3 pieces of carrots

Two non-destructive measuring methods (acoustic and impact method), a compression (cutter slice) test (Stable Micro System XT-2A Precision Penetrometer) and a dielectric method (HP4284A type precision RLC) were used for texture measurement changes of heat treated carrot samples.

Intact carrot samples were microwave heat treated and the same sample texture changes were measured by the four measuring methods. 1 cm thick carrot slices were used for one part of dielectric measurement and for the compression test.

3.4 In-vivo measurements using the acoustic method

Samples of two greenhouse grown tomato varieties, Preciza and Boderine were examined. In case of both varieties two plant per variety and two bunches per plant were examined. The experiment lasted more than two months and all together 57 samples were examined in every 2^{nd}-3^{rd} days.
During the acoustic measurement the tomato was excited on its equatorial surface and the acoustic response was recorded by a handheld microphone placed on the direct opposite side of the excitation.

Finite Element Modeling (Ansys 10.0) method (modal analysis) was used to choose the suitable acoustic stiffness coefficient describing the changes during growing and ripening. During the examination modal analysis was carried out. The frequency changes were modeled during development (diameter enlargement) and softening (Young modulus decrease) phenomena.

The SPSS^{TM} and the Excel program were used for statistical evaluation. The significant differences in the presented figures were evaluated at the 95 % significant level.

4 RESULTS AND CONCLUSION

4.1 Improving of the applicability of acoustic method

According to the results, the used acoustic stiffness measuring set-up (Fig.1.) was found to be suitable for the determination of the softening phenomena of individual pepper samples during post-harvest period. In case of paprika two excitation positions were examined: top (1) and shoulder part (2). In both case the product characteristic frequency peak of the measured acoustic response can be well separated from the other frequency peaks. One dominant frequency peak can be obtained by the excitation on the top of the pepper berry. In contrast to this, by the excitation on the shoulder part, other frequency peak can be seen (probably because of the excitation of other vibrational modes). There is no significant difference between the acoustic stiffness coefficients obtained by the excitation on the top and shoulder part of the berry. Because of the earlier mentioned observations it is advisable to excite the pepper berry on the top part.

Results of the Finite Element Modeling also supported that the stiffness change of pepper is characterized by the change of resonance frequency and there is a quadratic relationship between the two parameters ($S \sim f^2$). The results of the storage experiments supported also that the acoustic method is suitable for the determination of the stiffness of paprika and it is able to follow the paprika softening during storage.

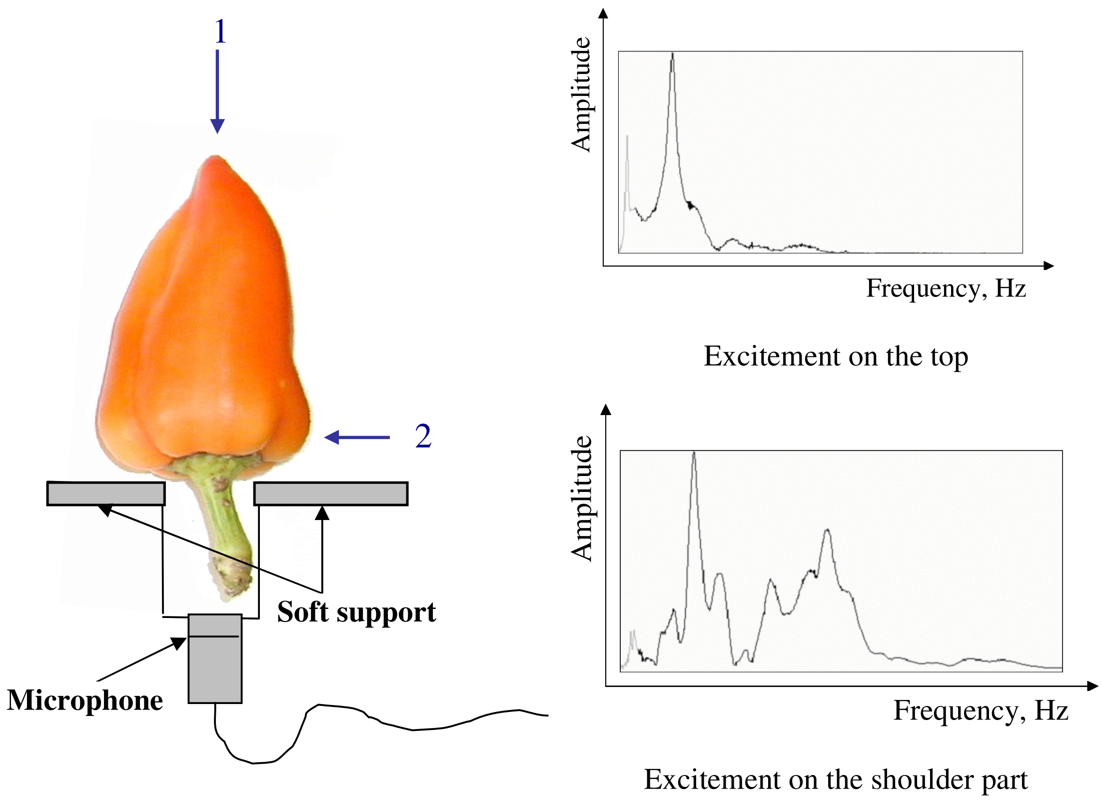

Fig.1.: Spectrum of acoustic response of paprika excited on different positions

4.2 Problems with the dynamic texture measurements – methodological analysis

It was determined with the impact method that depending on the measuring conditions the impactor's velocity has an effect on the impact stiffness coefficient in case of viscoelastic materials. In case of my measurements carried out with pepper and tomato, the change of impact stiffness coefficient caused by impact velocity was found to be negligible. In case of further measurements with other horticultural products, this effect was found to be 6-7 % depending on the variability of the measurements carried out manually. The impact stiffness coefficient's value depends on the material of the impactor's head. Accordingly, the product is measured to be softer by measuring its stiffness with a softer impactor head than by measuring its stiffness with a metal impactor head of similar geometry. The results obtained by the use of soft impactor head included all the information, which can be obtained by the use of metal impactor head. The main advantage of the use of soft impactor head is that the tissue change caused by repeated impact test can be reduced, so it provides with the possibility for less harmful measuring process.

4.3 Stiffness changes of carrot measured by acoustic and impact methods

Impact and acoustic stiffness measuring method were also found to be suitable for the determination of the changes of carrot samples caused not only by storage but by heat treatment as well. Results show that the different stiffness coefficients measured by the two different dynamic methods characterize different mechanical properties. Close relationship was found between the results obtained by the impact stiffness measurement and the traditional firmness measurement. The acoustic and the impact stiffness coefficient characterized the global firmness and the surface firmness of the samples, respectively. They showed different change during heat treatment. The carrot sample's surface showed a constant rate of softening due to the microwave heat treatment. In contrast to this, as a function of the used amount of microwave energy, the acoustic stiffness coefficient's change and the impedance change of the carrots slices can be estimated by a logistic (sigmoid) function.

4.4 In-vivo measurements using the acoustic method

Summarizing the results of the in-vivo measurements, the acoustic method was found to be suitable for measuring the stiffness changes of tomato during fruit development and ripening. This is due to that this method is non-destructive and it has high sensitivity. In case of tomato, the excitation along the equator and the detection at the opposite side of it were found to be a suitable measurement set-up. Using this set-up, an obvious and disturbance free acoustic response can be detected. Ansys Finite Element Modeling software was used for the selection of the suitable acoustic stiffness coefficient. The resonance frequency change during fruit development and softening can be characterized by a reciprocal ($f \sim d^{-1}$) and a quadratic function ($f \sim \sqrt{S}$). All the three acoustic stiffness coefficients were found to be suitable for the characterization of fruit softening. Taking into account the above mentioned information, the changes during development can be determined by the calculation of $S_2 = f^2 \cdot m^{2/3}$ and $S_3 = f^2 \cdot d^2$. The $S_1 = f^2 \cdot m$ was not found to be suitable for following the stiffness changes during fruit development. Therefore, in case of in-vivo measurement the S_2 and S_3 formulas can be used for tomato stiffness calculation. According to the results, the tomato fruit is softening continuously during fruit development and ripening (Fig.2.). Having reached a certain time and age during development, the fruit stiffness rapidly decreases. In the very same physiological phase the color of the crops changed from green to red.

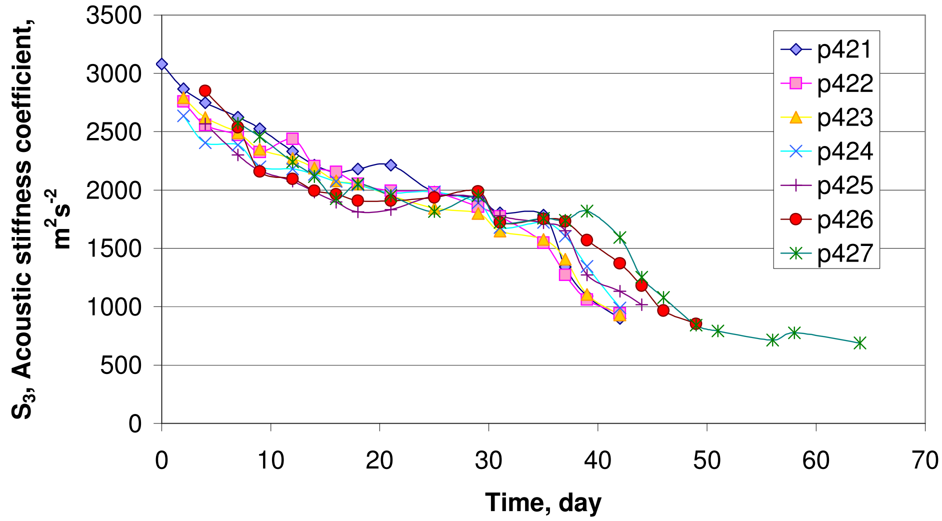

Fig.2.: The changes of acoustic stiffness coefficient (S_3) of tomato during development and ripening

5 PROPOSALS FOR FURTHER SCIENTIFIC ACTIVITY AND FOR PRACTICAL APPLICATIONS

Further research is proposed in the following fields:

- Determination of stiffness changes of further fruit and vegetable varieties during ripening by acoustic response technique (in-vivo measurement) in order to get more precise information about the physiological processes. It is really advisable to complete the stiffness measurements with surface color measurement in order to compare these two parameters.
- Methodological examination of acoustic stiffness measurement and precise evaluation of the experimental conditions' effect on stiffness coefficient.
- Design of acoustic and impact measurement method based sorting line. Construction of on-line classification equipment and its application for classification of fruits and vegetables in to different quality classes.
- Investigation of textural changes of horticultural products affected by different storage conditions. Definition of the descriptive model of softening phenomena. Determination of the optimal storage time using the evaluated model.
- Determination of the relationship between the stiffness coefficients obtained by dynamic and compression methods.
- Investigation of the applicability of acoustic stiffness measuring method for further non-spherical fruits and vegetables.
- Establishment of a special decision-supporting expert system based on non-destructive stiffness methods for the qualification of different horticultural products.

6 NEW SCIENTIFIC RESULTS

1. Measurement set-up and measuring method were developed for paprika stiffness measurement by acoustic response measuring method. It was proven that the characteristic acoustic response of paprika sample is well detectable and it can be clearly separated from the other resonance frequency peaks.
2. It was proven by experiments and Finite Element Modeling that the change of the resonance frequency induced by acoustic excitation represents well the stiffness changes of paprika. According to this statement it is possible to follow the softening phenomena of the individual paprika sample. The results of the Finite Element Modeling confirmed that there is a quadratic relationship between the resonance frequency and the stiffness (Young modulus) of the paprika model ($f^2 \sim S$).
3. It was confirmed that the stiffness measured by acoustic and impact method characterize different mechanical properties in case of heat treated carrot as well. The acoustic stiffness coefficient characterizes the global stiffness of the sample, while the impact stiffness coefficient characterizes the surface stiffness of the sample. Close relationship (R^2=0,79) was found between the results of the impact method and the conventional compression firmness measuring method.
4. The changes of acoustic stiffness coefficient of the whole carrot caused by microwave heat treatment and the changes of the impedance of the carrot slices were determined. The changes of these parameters can be described by a logistic (sigmoid) function versus the energy of heat treatment. The parameters of the described model were determined for the measured samples.
5. The effect of the velocity of the impact hammer on the impact stiffness coefficient was determined in case of viscoelastic materials. This effect depends on species and variety. In case of paprika and tomato the change of the impact stiffness coefficient caused by the variability of the impact velocity was less than 1 % in most of the cases. In case of apple and onion this effect was maximum 7 % depending on the impact velocity variability of the measurement carried out.
6. In case of impact measurement method the material of the impactor's head has a definite effect on the calculated impact stiffness coefficient (obviously the use of deformable impactor head results in smaller resultant stiffness coefficient). However, it was proven that if the sample's high sensitivity requires the use of elastic impactor head, the collected results contain all the information which could be obtained by the use of non-deformable (metal)

impactor as well. Therefore, the use of the elastic impactor head offers the possibility of classification and the determination of the stiffness changes.

7. Measurement set-up and measuring method were developed for the in-vivo measurement of tomato stiffness changes by acoustic method during tomato development and ripening. It was proven that the characteristic frequency peak can be separated definitely from the other resonance peaks and the characteristic resonance signal is of high reproducibility (R^2=0,98).
8. In case of in-vivo measurement of tomato stiffness the continuous decrease of acoustic stiffness coefficient of tomato berry was determined during development and ripening. The softening is a nonlinear function of time, after obtaining a certain point of development the stiffness of tomato berry intensively decreases. Parallel to these phenomena the surface color of the tomato berry turns from green to red.
9. According to the results of the Finite Element Modeling during the simulated development and simulated softening of tomato model the characteristic resonance peak change can be described with a reciprocal ($f \sim d^{-1}$) and with a square root ($f \sim \sqrt{S}$) function, respectively. Consequently, it was determined that the changes during development could be described by the $S_2 = f^2 \cdot m^{2/3}$ and the $S_3 = f^2 \cdot d^2$ functions, while the $S_1 = f^2 \cdot m$ was not found to be suitable for the characterization of the stiffness changes during development.

7 PRESENTATIONS AND PUBLICATIONS PUDLISHED IN THE SUBJECT OF DISSERTATION

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