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Nondestructive Quality Evaluation for Fruits and Vegetables

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Abstract- The term quality implies the degree of excellence of a product or its suitability for a particular use. Quality of produce encompasses sensory properties such as appearance, texture, taste and aroma, and mechanical properties, chemical constituents, nutritive values, functional properties and defects. Product quality and quality evaluation methods are naturally extremely important. Quality evaluation of fruits and vegetables can be of destructive and nondestructive types. In the former the entire fruit is destroyed while evaluating the quality. In nondestructive quality evaluation the fruits and vegetables are not destroyed while evaluating its quality. Current and new technologies are being utilized to develop better nondestructive methods for measuring fresh fruit and vegetable quality. Nondestructive quality evaluation of fruits and vegetables can be classified into mechanical, optical, electromagnetic and dynamic techniques. There are different techniques under these categories.

Keywords- Nondestructive quality evaluation, impact tests, near infrared technology, dynamic tests, optical techniques

I. INTRODUCTION

Fruits and vegetables are increasing in popularity in the daily diets of people of both developed and developing countries. The decisions concerning harvesting, maturity, ripeness and quality are based mostly on subjective and visual inspection of the fruit's external appearance. Safety assurance in agri-products is being more crucial with the liberating international trade system and globalization for capturing the global market.

Quality components of fruits and vegetables are classified into the external such as size, colour, shape, external defects etc. and the internal such as sugar content, acid content, firmness, maturity, internal breakdowns etc. Fresh fruits and vegetables have a specific characteristic in their internal and external factors. Numerous techniques for evaluating the above external quality factors are now available commercially. Internal quality factors such as maturity, sugar content, acidity, oil content, and internal defects, however, are difficult to evaluate. Methods are needed to better predict the internal quality of fruits and vegetables without destroying them.

Methods to measure fruit quality can be of destructive and non-destructive. With destructive methods, a sample of fruit must be measured in order to estimate the quality of a batch: besides the economical loss, due to fruit destruction, there is also the problem of how the sample is representative of the whole batch.

If we use the internal quality factors and do not destroy the fruit while measuring them, such approaches are referred to as nondestructive quality evaluation. By applying this method it can overcome possible discrepancies between different batches and samples of fruit, without destroying a certain amount of sample fruit.

II. NONDESTRUCTIVE QUALITY EVALUATION

The nondestructive methods could be divided into two types, one is done at off-line state and the other is at on-line state. In other words, the former is a method free from the time limit in measurement of fruit quality and the latter is the one limited by time. Recently, there has been an increasing interest in non-destructive methods of quality evaluation, and a considerable amount of effort has been made in that direction.

Many kinds of nondestructive techniques have been developed to measure quality components of biological products including fruits and vegetables, and can be classified into mechanical, optical, electromagnetic and dynamic methods according to their measurement principals. It is noted that most of the quality components listed could be measured at off-line state but not at on-line state on that spot.

Classification of nondestructive quality evaluation

1) Mechanical
   a) impact tests
2) Optical
   a) image analysis
   b) reflectance, transmittance and absorbance spectroscopy
   c) laser spectroscopy
   d) visible/near infrared spectroscopy
3) Electromagnetic
   a) Impedance
   b) Magnetic resonance/magnetic resonance imaging
4) Dynamic
   a) vibrated excitation
   b) sonic
   c) ultrasonic
   d) x-ray image and CT

2.1 Mechanical non-destructive methods

Mechanical non-destructive methods aim at measuring texture characteristics, mainly firmness. It includes low mass impact tests: impact parameters are detected by accelerometers, or resonance frequency is detected by a microphone and technique using electronic noses. The resonance frequency generally changes with ripening, and measures a property of the whole fruit.

2.1.1 Gas sensors arrays: electronic noses

The electronic noses try to simulate the functioning of the olfactory system. They are made of an array of chemical and electronic sensors with partial specificity and of a system of pattern recognition, able to recognize simple and complex odours. There are many types of sensors, which, based on different principles, react with a change in their properties: metal oxide semiconductors of different types and conducting organic polymers change their electrical properties when absorbing volatile compounds; sensors based on quartz crystal microbalance change their mass, so changing their resonance frequency, which is measured. Different types of sensors differ according to repeatability, to reaction and recover time, to selectivity and to sensitivity to humidity. Electronic noses can recognize classes of compounds [2]. Each sensor reacts to a different set of volatile compounds; the pattern of the combined responses of all the sensors gives a “fingerprint” of a compound or a mixture. The electronic nose cannot analyze and determine the different volatile compounds, like a gas chromatograph, because its response is not unique. It is useful to detect deviations from a standard, whose fingerprint is well known, or to follow changes in times.

2.1.2 Impact tests

Fruit firmness can be estimated by different techniques including the measurement of variables extracted from the analysis of impact forces and the rebound technique [12]. There are many ways of using impact sensors, such as: a) hitting the fruit with some element that includes the sensor; b) putting the fruit over a load cell and letting a weight fall on it; c) placing the fruit on a flat plate with a load cell located beneath it. A technique was developed for measuring firmness that involved impacting fruit with a pendulum. This system, with several modifications, is still used to measure damage in tomatoes [9]. There is a vertical impact sensor to measure the response of fruit to impacts. The sensor consisted of a small, semi-spherical mass with an accelerometer, which was dropped from different heights onto the fruit. Manual impact sensors, lateral impact sensors are some other sensors used as mechanical measures [8, 9].

2.2 Optical techniques

Optical properties are concerned with the response of a matter to UV (180 nm-130 nm) light, which are characterized by reflectance, transmittance, absorbance, or scattering. The main optical techniques being used are image analysis to measure size, shape, colour, external defects etc. near infrared spectroscopy to measure soluble solid content, dryness, firmness, acidity etc. reflectance, transmittance and absorbance spectroscopy to measure colour, chemical constituents, internal defects etc. and laser spectroscopy to measure firmness, visco-elasticity, defects, shape etc.

2.2.1 Near infra-red reflectance spectroscopy

VIS/NIRS method is attributed to the absorption phenomena of certain wavelength by certain molecules. Among optical techniques, continuous-wave near infra-red reflectance spectroscopy (NIRS) is gaining increasing popularity for the quality assessment of fruit, as in the last two decades these techniques have provided encouraging results for estimating several quality parameters in fruit. NIRS has been used for estimating soluble solids content, but also other properties: dry matter, firmness, acidity. Generally the estimation for soluble solids is satisfactory and consistent, while for firmness and acidity the results are more variable.

One of the important differences between NIR analysis and other spectroscopic methods is that NIR spectroscopy is uniquely qualified to provide analysis capabilities to the food and related industries, through its interaction with the organic molecular material of foodstuffs. Most food is organic, containing C-H, C-O-H and C-N-H, etc. These bonds interact in a measurable way with the NIR portion of the spectrum. NIR light is energetic enough to bring atoms within a molecule in vibration relative to each other. These interactions occur at the speed of light providing extremely rapid information gathering capabilities [7]. NIR range is the only electromagnetic spectrum that this particular measurable interaction occurs in. NIR creates a faster, safer work environment and does not require chemicals. When light comes in contact with a biological material, the photons of light can interact with the material at the molecular level. Molecules have discrete energy states and light can cause a molecule to change from one energy state to another if the energy in the photon matches the energy required to elevate the molecule from one energy state to another [4]. Thus when light comes in contact with a molecule, it can either be absorbed (because the energy level of the light matches the energy level required to excite the molecule to a higher energy state) or reflected from or transmitted through the molecule. The wavelength of the light absorbed by the molecule indicates the type of molecule (e.g. water, sugar, starch, fat, pigment, etc.) due to the unique relationship between the energy of the light and the energy states of the molecule [10].

2.2.2 Time-resolved reflectance spectroscopy

Time-resolved reflectance spectroscopy (TRS) has been investigated as a novel non-destructive technique for quality evaluation of fruits. TRS yields a complete optical characterization of the investigated sample through simultaneous estimation of the absorption coefficient and the transport scattering coefficient. This is accomplished by interpreting the attenuation and broadening experienced by a short laser pulse with a proper theoretical model while travelling in a diffusive medium, such as most fruits. Optical properties of fruits constitute a complex system, therefore light (electromagnetic radiation) is affected by many factors in its interaction with fruit tissues. Absorption and scattering are therefore complex effects. However, to a first approximation, the absorption coefficient is primarily dependent on tissue components(water, chlorophyll, sugars), while the transport scattering coefficient is dependent on tissue microscopic structure (cells, fibers). Moreover, key advantages of TRS applied to fruits and vegetables include insensitivity to skin colour and properties and penetration into the pulp of fruits to a depth of more than 2 cm. As the name implies, light reflected from an illuminated surface of the commodity is measured in this system. This technique is particularly effective with fruits that have uniform external colour so that the quality condition of the fruits can be predicted from reflectance reading [6].

Currently, this technology is used in grading lines of packing houses to sort tomatoes, oranges, lemons and apples according to defined colour categories. It has recently gained increasing use in biomedicine for the non-invasive investigation of biological tissues. Similarly, it has been used for optical characterzation of fruit. In TRS, a short laser light pulse is injected into the medium to be analyzed. Due to photon absorption and scattering events, the diffusely reflected pulse is attenuated, broadened and delayed [5]. In most biological tissues such as fruit and vegetables the depth of the probed volume is of the same order as the source-detector distance, which is 1-2 cm. Consequently, the measurements probe the bulk properties, not the superficial ones, and may provide useful information on internal quality. The novelty with TRS is the use of a pulsed laser source, and the detection of the temporal distribution of re-emitted photons. This allows one to measure separately both μ_a and μ_s' in the pulp of the fruit averaged over the probed medium. The time required for one TRS measurement is now one second with a manual portable prototype, but the technique could be adapted for on line measurement, reducing acquisition time to ten milliseconds.

2.2.3 Laser spectroscopy

Laser absorption spectroscopy (LAS) in the mid-infrared region offers a promising new effective technique for the quantitative analysis of trace gases in human breath. LAS enables sensitive, selective detection, quantification and monitoring in real time, of gases present in breath. It summarizes some of the recent advances in LAS based on semiconductor lasers and optical detection techniques for clinically relevant exhaled gas analysis in breath, specifically such molecular biomarkers as nitric oxide, ammonia, carbon monoxide, ethane, carbonyl sulfide, formaldehyde and acetone. The mid-infrared spectral range is ideal for tunable laser absorption spectroscopy (LAS) since most molecular gases possess strong, characteristic fundamental rotational vibrational lines [3]. High-resolution LAS can resolve absorption features of targeted molecules and selectively access optimal spectral lines at low (100 Torr) pressure without interference from CO_2 and H_2O to achieve high levels of trace gas detection sensitivity and specificity. Avoiding CO_2 and H_2O interferences is particularly important in the development of biomedical gas sensors for breath analysis.

The time domain reflectance spectroscopy procedure provides a complete optical characterisation of a diffusive sample as it estimates (at the same time and independently) the light absorption inside the tissues and the scattering across them. The light source is a laser, monochromatic, but tunable at several wavelengths, and with a very short pulse rate. The light is directed on to the surface of the fruit through the intact skin using fibre optics positioned perpendicularly to the central part of the fruit. The light penetrates the tissues and part of it is reflected out of the sample at a particular region adjacent to the transmission point.

This portion of reflected light was recovered with the collecting fibre optics placed at about 20 mm in parallel to the transmission ones. The three-dimensional region formed by the light which is capable of entering the collecting fibre is constructed by the optical paths of the photons with greater probability of being recovered after suffering internal body reflection.

2.3 Electromagnetic techniques

It includes impedance technology to measure moisture contents, density, sugar content, density and internal cavity and nuclear magnetic resonance and magnetic resonance imaging (MRI) to measure sugar content, oil, moisture content, internal defect and structure.

2.3.1 Nuclear magnetic resonance (NMR) techniques

The nuclear magnetic resonance technique, often referred as magnetic resonance imaging (MRI), involves resonant magnetic energy absorption by nuclei placed in an alternating magnetic field. The amount of energy absorbed by the nuclei is directly proportional to the number of a particular nucleus in the sample such as the protons in water or oil.

Certain nuclei, including 1H, 13C, 31P and 23Na, have a magnetic moment and align along a strong static magnetic field. The 1H magnetic resonance is of greatest horticultural interest. A weak pulse of the proper radiofrequency (RF, based on magnetic field strength) will cause the net magnetic moment to rotate 90°. When the RF signal is removed, the moment loses energy and relaxes back to its previous position. Energy released by relaxation induces an RF signal in a receiver coil. Energy loss is differential and is based on the environment surrounding each nucleus Of particular interest in horticultural applications, areas of greater free water content are brighter than surrounding tissues in MRI, so that disorders involving water distribution-water core, core breakdown, chilling injury, bruising, decay, presence or feeding of insects, etc. can be visualized [11].

MRI has been used to show morphology, ripening, core breakdown, seeds or pits, voids, pathogen invasion, worm damage, bruises, dry regions, and changes due to ripening, heat, chilling and freezing. Currently, MR and MRI are not practical for routine quality testing. MR equipment is expensive and difficult to operate; but, like all technologies, it is becoming cheaper, faster and more feasible for research and specialized applications. MR techniques have great potential for evaluating the internal quality of fruits and vegetables.

2.4 Dynamic techniques

It includes vibrated excitation to measure firmness, visco-elasticity and ripeness, sonic technique to measure firmness, visco-elasticity and internal cavity and density, ultrasonic technique to measure internal cavity and structure, firmness and tenderness and x-ray image and CT to measure internal cavity and structure and ripeness.

2.4.1 Vibrated excitation techniques

The internal quality of fruit can be non-invasively tested using systems based on vibrational characteristics. Acoustic impulses were used to detect internal hollows; the change in the signal revealing the problem. Frequency spectrum variables were analysed for their potential as non-destructive predictors of this defect. The band magnitude variables, obtained from the integral of the spectrum magnitudes between two frequencies, best predicted internal disorders. Experimental modal analysis was used to investigate the vibrational performance of fruits and vegetables and to determine the best positions for the impact point and response measurement microphone. A first type spherical mode and its resonant frequency was the best indicator of internal quality problems [11]. Finite element modal analysis was performed to establish a watermelon shape/characteristics model and to compare theoretical and experimental results. When an object is excited in the audible or no audible range of frequencies it responds by vibrating. The amplitude peaks obtained in the frequency spectrum are its resonant frequencies, the appearance of which is related to the elasticity, density, size and shape of the object. The resonant frequencies of some fruits and vegetables (apples, melons, peaches, tomatoes etc.) have been associated with firmness, and stiffness or firmness coefficients have been recorded for them (Jamal, 2012).

2.4.2 Ultrasonic techniques

The nondestructive ultrasonic measurement system was depended for the assessment of same transmission parameters which might have quantitative relation with the maturity, firmness and other quality - related properties of fruits and vegetables. Fruit important features can be evaluated by ultrasonic nondestructive method. This method is based on energy transmission into product and evaluation of response energy [8]. When the system implementing an ultrasonic method for nondestructive measurements of internal quality of fruits and vegetables was tested by pair of ultrasonic transducers, one acts as transmitted and the other as a receiver for some transmission of sound wave through the fruits peel and flesh and the reception of the transient signal.

Ultrasonic waves can be transmitted, reflected, refracted or diffracted as they interact with the material. Wave propagation velocity, attenuation and reflection are the important ultrasonic parameters used to evaluate the tissue properties of horticultural commodities. However, because of the structure and air spaces in fruits and vegetables, it is difficult to transmit sufficient ultrasonic energy through them to obtain useful measurements

Ultrasonic measurements could be used for firmness determination in some fruits but that a more powerful ultrasonic source is required to penetrate others. Despite numerous studies, few applications have developed. This method is difficult to use in fruit quality determination since it is strongly attenuated when travelling through fruit tissues and as a result the ultrasound waves cannot penetrate deeply into the fruit [13].

2.4.3 X-ray and CT

X-ray imaging is an established technique to detect strongly attenuating materials and has been applied to a number of inspection applications within the agricultural and food industries. In particular, there are many applications within the biological sciences where we wish to detect weakly attenuating materials against similar background material. X-ray computed tomography (CT) has been used to image interior regions of fruits with varying moisture and, to a limited extent, density states. The images were actually maps of x-ray absorption of fruit cross sections. X-ray absorption properties were evaluated using normal fruits alternatively canned and sequentially freeze-dried, fruit affected by water core disorder, and normal fruits freeze-dried to varying levels. The results suggested that internal differences in x-ray absorption within scans of fruit cross-sections are largely associated with differences in volumetric water content. Similarly, the physiological constituents have been monitored in fruits by CT methods in which x-ray absorbed by the fruits is expressed in CT number and used as an index for measuring the changes in internal quality of the fruit. Relationships between the CT number and the physiological contents were determined and it was concluded that x-ray CT imaging could be an effective tool in the evaluation of fruit internal quality [11].

X-ray has been explored for inspecting the interior of agricultural commodities. The intensity of energy exiting the product is dependent upon the incident energy, absorption coefficient, density of the product and sample thickness. Due to the high moisture content in fruits and vegetables, water dominates X-ray absorption.

III. CONCLUSION

Quality is not a single, well-defined attribute but comprises many properties or characteristics. Statistical combination of measurements by several sensors will increase the likelihood of predicting overall quality. However, sensor testing and calibration must include a wide range of conditions. It is important that what is really being detected is understood so the limitations are appreciated. Of course, there are different requirements for laboratory and industry applications.

Optical methods are being developed for on-line detection of surface defects based on optical measurements in the visible or NIR regions. Optical systems, especially in the NIR region, and newer software make it possible to detect carbohydrates, proteins and fats that may improve quality indexes. It is likely that on-line NIR sensing of soluble solids will be routine in the near future. X-ray inspection systems are now used to detect internal defects on-line in some limited applications, but the increasing sensitivity of the equipment and the development of rapid image processing could soon make this technology more available. MRI has great potential for evaluating the quality of fruits and vegetables. The equipment now available is not feasible for routine quality testing. Compared with other optical techniques, TRS has the merit of measuring well-defined, physically based properties. Moreover, TRS explores a volume within the fruit, without being affected by surface properties. NMR, x-ray CT and NIR techniques may be useful for a large volume of work in agriculture, especially for evaluation of qualities such as maturity, internal quality of fruit and conditions of food materials after processing (Abbott, 1999). These techniques, although give a correct picture and precise measurement of parameters, are not convenient for small businesses. Their higher cost restricts application to large entrepreneurs and developed countries only.

With the development of such a new technique, a few changes in production and marketing of fresh product have been occurred. Possible applications of this non-destructive technique for commercial purposes that until now can be envisaged are: a) to detect internal defects in fruit, even following up their formation; b) to grade fruit according to maturity, predicting their potential shelf life in the case of nectarines. So a great deal of potential applications can be envisaged for this technique when a simpler instrumentation will be available, also for on-line grading of fruits.

REFERENCES

[1] Abbott, J. A. 1999. Quality measurement of fruits and vegetables. Postharvest Biology and Technology.
[2] Berna A. 2010. Metal Oxide Sensors for Electronic Noses and Their Application to Food Analysis. sensors 10: 3882-3910
[3] Berns, R.S. 2000. Billmeyer and Saltzman principles of color technology, Third ed. John Wiley & Sons, New York.
[4] Bureau, S., D. Bertrand, B. Jaillais, P. Reling, B. Gouble, C.M.G.C. Renard, B. Dekdouk, L.A. Marsh, M.D. O'Toole, D.W. Armitage, A.J. Peyton and J. Alvarez-Garcia. 2013. Fruit Grading: Development of a fruit sorting technology based on internal quality parameters. NIR 2013 - 16th International Conference on Near Infrared Spectroscopy, la Grande-Motte, France.145- 148.
[5] Cubeddu, R., Pifferi, A., Taroni P., and Torricelli, A.2002. Measuring fresh fruit and vegetable quality: advanced optical methods.Woodhead Publishing Ltd and CRC Press, LLC.
[6] Ignat, T. 2012. Non-destructive methods for determination of quality attributes of bell peppers. PhD Thesis, Department of Physics-Control, Faculty of Food Science, Corvinus University of Budapest.
[7] Itoh, H., Kanda, S.H., Matsuura, K. S. and Sasao A. 2010. Measurement of nitrate concentration distribution in vegetables by near-Infrared hyperspectral imaging. Environment Control in Biology. 48: 31-43.
[8] Jamal N.2012. Application of Acoustic Properties in Non – Destructive Quality Evaluation of Agricultural Products.International Journal of Engineering and Technology.
[9] Khalifa, S., Mohammad H. K. and Behrouz T. 2011. Usage of fruit response to both force and forced vibration applied to assess fruit firmness- a review. Australian Journal of Crop Science. 5(5):516-522.
[10] Liew, C.Y. and Lau, C.Y.2012. Determination of quality parameters in Cavendish banana during ripening by NIR spectroscopy, International Food Research Journal 19(2): 751-758.
[11] Shyam, N. J. and Matsuoka, T.2000. Non-Destructive Techniques for Quality Evaluation of Intact Fruits and Vegetables. Food Sci. Technol. Res., 6 (4), 248–251.
[12] Yesim, B.Y.2012. Comparison of nondestructive impact and acoustic techniques for measuring firmness in peaches.Journal of Food, Agriculture & Environment Vol.10 (2): 180-185.www.world-food.net.
[13] Zerbini, P.E.2006. Emerging technologies for nondestructive quality evaluation of fruit. Journal of Fruit and Ornamental Plant Research.

