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REVIEW PAPER

Non-destructive Quality Monitoring of Fresh Fruits and Vegetables

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ABSTRACT

Quality determines the shelf life as well as selling price of fresh fruit or vegetable and therefore, quality monitoring and testing of fresh commodities have paramount importance in their postharvest handling and supply chain management. Most of the methods used to assess fruits and vegetables quality are destructive in nature. Now-a-days, various mechanical, optical, electromagnetic, and dynamic non-destructive methods are gaining importance due to ease in operations, faster turn over and reliability. Some of the non-destructive techniques (NDT) are currently being used in laboratories, research institutions and food packaging and processing industries, whereas, some methods are still at developmental stage. Various NDT with respect to their principle and applications such as impact test, electronic nose, time-resolved reflectance spectrometry, near infrared spectroscopy, nuclear magnetic resonance, X-Ray, ultra sonic, acoustic impulse response method, electrical conductivity methods etc., are discussed in this review.

Keywords: Fruits; Vegetables; Non-destructive techniques; Postharvest; Quality

1. INTRODUCTION

Quality is a term which exhibits the degree of excellence, a high standard or value. Quality of food may be defined as the composite of those characteristics that differentiate individual units of a product, and have significance in determining the degree of acceptability of that unit to the user. Quality of fruits and vegetables is based on its sensory properties, nutritional value, safety and defects. Fruits and vegetables with superior sensory and nutritional qualities have high economic value[1]. The quality is mostly based on the evaluation of various external and internal factors. Size, shape, colour, gloss, firmness, texture, taste and freedom from external defects such as visible blemishes, dullness, etc., are various external quality factors of importance. Fruit size is assessed by using various parameters such as diameter of the fruit, its volume and its weight[2]. Firmness is a qualitative concept and is the sensation of texture in mouth. Fruit firmness is the indirect parameter used to measure fruit maturity or ripeness which helps to establish optimum transportation condition and period[3-4]. Texture is a sensory attribute which is measured directly by sensory means. Internal quality factors include maturity of fruits, sugar content, acidity, fat content, pigments, colour, dry matter, pectic substances and free from internal defects such as internal bruises, pits, cavities etc. Colour, acidity and dry matter are various variables used to measure maturity of fruits.

Secondary processing of fruits and vegetables are carried out to increase the shelf life, which results in various characteristic changes such as physical changes as well as aerodynamic, thermal and hygroscopic properties[5-7]. Freeze storage of fruits results in the formation of ice crystals. The ice crystals formed affects the texture of fruits negatively and decreases its sensory acceptability. Internal quality evaluation of fruits and vegetables highly affects post-harvest period[4]. The colour and firmness of fruits affect the product appearance and consumer acceptability. Hence, they are important quality factors to growers and processors[8-9].

Subjective and visual inspection helps to study the maturity, ripeness and quality of fruits and vegetables. This in turn helps to decide the harvesting time[10]. Quality evaluation methods can be classified as on-line and off-line state[11]. Majority of the methods used to assess fruit quality are destructive, time consuming, labour intensive, cost intensive and biased. Destructive methods of quality evaluation are not suitable in industries such as packaging industry as it ruptures the fruit tissue and evaluation of whole lot cannot be done.

Non-destructive methods are effective than traditional conventional methods as non-destructive methods are mainly based on physical properties which correlate well with certain quality factors of fruits and vegetables[4]. Mechanisation and automation in food industries is increased as machines are more consistent than humans, reduces the labour cost and is non-destructive. Acoustic, mechanical and optical non-destructive methods are adopted in fruit packaging industries to determine fruit quality[12]. Non-destructive methods are advantageous over traditional destructive methods as they do not rupture the fruit tissue, can be used to assess internal variables of fruits. It is useful in sorting superior quality fruits from substandard fruits based on their size and shape in online system and sampling of all fruits or vegetables is carried out

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which ensures maximum quality. Studying both physical and chemical parameters using single NDT is difficult and depends on variables such as chemical composition, parameters to be assessed and their physical structure. Hence, various methods are used for external and internal quality evaluation. The quality parameters are assessed directly in cases such as in detection of internal defects, or indirectly by correlating the results obtained on assessing other chemical or physical characteristics, for example, measurement of maturity is based on colour or firmness (Tables 1 and 2).

Various non-destructive methods used in the quality evaluation can be classified as:

(a) Mechanical methods
(b) Optical methods
(c) Electromagnetic methods, and
(d) Dynamic methods

Table 1. Non-destructive methods to determine particular quality characteristics of fruits and vegetables

Non-destructive technique	Quality characteristics
Impact test	Firmness, internal damage, etc.
NMR	Maturity, pit detection, freeze damage, heat injury, worm damage, sugar content, infections, moisture & oil content, etc.
MRI	Morphology, Maturity, Core breakdown, Pit detection, worm damage, freeze damage, heat injury, etc.
X-ray	Moisture content, density states, freeze damage, internal browning, bruises, tissue damage, tunnel or pit detection, presence of insects, etc.
NIR	Soluble solids, firmness, acidity, dry matter, Sugar content, Freeze damage, post-harvest defects, rapid analysis of moisture, fat & protein content, etc.
Acoustic	Firmness, internal defects, internal cavity detection, etc.
UV-VIS spectroscopy	Carotene content, etc.
Fluorescence spectroscopy	Freshness, ripeness, surface bruises, etc.
Ultrasound	Maturity, defects, sugar content, firmness, moisture & oil content, etc.

2. MECHANICAL METHODS

Mechanical methods include low mass impact test, microphone test and electronic nose methods. It is useful in the assessment of fruit texture by measuring stiffness and elastic properties which are related to turgor pressure and water loss, than to mechanical strength of cell wall and middle lamella[11,13].

2.1 Mechanical Thumb Method

It depends on the response of fruits to force. Principle of this method is similar to that of destructive Magness-Taylor tester method where fruit firmness is calculated in a destructive manner by introducing a cylindrical head into the flesh of a peeled fruit to measure the maximum penetration force[2,14]. It was first used by Schomer and Olsen[15]. The mechanical thumb developed had a contact head which replaced the standard plunger on the Magness-Taylor tester, and penetration was limited to 1.27 mm. Mechanical thumb helps to compare the colour of fruits by means of difference in fruit firmness. Mizrach[16], *et al.* has successfully distinguished red tomatoes from green tomatoes by using this method. Mizrach[17], *et al.* used a small 3 mm diameter flat-head pin onto the peel of oranges and tomatoes to estimate firmness of oranges and tomatoes by measuring the force and deformation of the peel (Fig. 1).

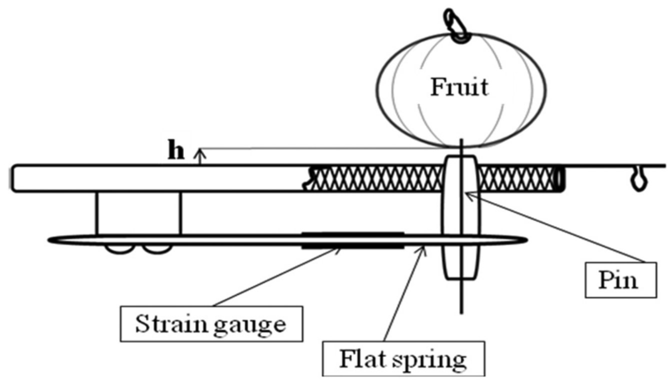


Figure 1. A typical mechanical thumb equipment.

2.2 Gas Sensor Arrays: Electronic Nose

Electronic nose consists of chemical and electronic sensors which try to stimulate the functioning of olfactory system. An electronic nose consists of a sensor, data processing unit, software with digital pattern-recognising algorithms and reference library[18-21] (Fig. 2). Organic polymers, metal oxides, quartz crystal microbalance and gas chromatography (GC) are the various sensors used. Sometimes, GC is combined with mass spectroscopy (MS). The sensors interact with volatile compounds/odours non-selectively to produce chemical or physical changes which produces signal and the signals produced are read by the computer[22]. The response given by the sensors to each sample is called as ‘electronic finger print’ of a compound or mixture[23]. The sensors recognise the odour depending on the response pattern of a compound to sensors with reference to the known standard finger print[11]. Computed results are interpreted by multivariate statistics such as linear discriminant analysis (LDA), discriminant function analysis (DFA), hierarchical cluster analysis (HCA), soft independent modelling of class analogy (SIMCA) and partial least squares (PLS). Artificial neural networks (ANN) are used for liner responses[22]. It is useful in determining fruit firmness, freshness and quality evaluation during shelf-life studies.

3. OPTICAL METHODS

Optical properties of fruit are based on reflectance, transmittance, absorbance, fluorescence or scattering of light. Soluble solid content (SSC), acids, starches and overall maturity of fruits can be analysed by using spectral-optical methods non-destructively. This method includes image analysis (analysis of size, shape, colour and external defects); visible/near infrared spectroscopy (VIR); laser spectroscopy; reflectance, transmittance and absorption spectroscopy.

Table 2. Fruit and vegetable quality monitoring using NDT methods

NDT method	Parameter	Fruit/ Vegetable	Type/variety	Observations	Reference
Acoustic impulse	Firmness	Apricot	Green mature Half ripe Ripe Over ripe	Acoustic firmness index decreased with increase in ripening stage	61
Acoustic impulse	Firmness (Dominant frequency and damping ratio)	Papaya	Unripe Semi-ripe Ripe Over-ripe	Dominant frequency decreased whereas damping ratio increased with ripening	62
Acoustic impulse	Firmness	Apple	On tree During shelf-life	Slight alteration in the frequency on tree, whereas, decrease in frequency during storage	63
Laser induced fluorescence (LIF)	Firmness	Apple	Sunlit Shaded	Same values were obtained for both the cases	64
Electronic nose (EN)	Maturity	Apple	Immature Mature Over mature	Electronic nose responses were influenced by maturity of fruit and the apples were classified into three maturity groups depending on EN response.	65
Acoustic impulse	Firmness	Apricot	Green mature Half ripe Ripe Over ripe	Acoustic firmness index decreased with fruit maturity	61
VIS-NIR spectrophotometer	Sugar content & Chlorophyll content	Banana	Unripe Ripe Very ripe	Internal fruit sugar contents (glucose, sucrose, fructose) were predicted with high accuracy. Whereas, Chlorophyll content decreased with ripening.	66
Ultrasonic	Chilling injury	Tomato		Chilling injury increased the attenuation of ultrasonic waves	67
VIS-NIR spectrometer	Soluble solids content	Orange		Mean value of 13.17º Brix was obtained. Both Destructive (conventional) and Non-destructive methods exhibited similar values.	68
Electronic nose	Storage shelf-life	Tomato		Correlation between the Measured and predicted values showed poor prediction	69
Electronic nose	Freshness prediction	Peaches	Total soluble solids & Firmness	Total soluble solids increased and firmness decreased with decreasing freshness	70

3.1 Visible / Near Infrared Spectroscopy

Near Infrared Spectroscopy (NIR) covers the range of 780-2500 nm in the electromagnetic spectrum. It is more suitable to practical application and helpful in sorting and grading of fruits. This method helps to evaluate fruit maturity by measuring the skin colour of fruits such as banana, apple, tomato and mango (Fig. 3). Skin colour of fruits depends on the quantity of chlorophyll present in the skin. The changes in pigments present in fruits help to determine the maturity. Chlorophyll content decreases with the fruit ripening[24]. NIR method has been successfully used in fruit firmness measurement and detection of visible blemishes[25-26]. Soluble solid content, dry matter, hygroscopicity, firmness, sugar content, acidity etc., are measured using this method and it does not require sample preparation[10-11]. Estimation of soluble solid content (SSC) by using NIR is satisfactory and consistent, whereas, the results for firmness and acidity were found to be more variable[27].

3.2 Time-resolved Reflectance Spectrometry

This method is mostly suitable for optical characterisation of highly diffusive media[28]. It involves the penetration of light in to a diffusive medium which depends on the optical properties of the medium and on the source-detector distance. In case of fruits and vegetables, the depth of the probe volume is of the same order as the source detector distance, i.e. approximately 1-2 cm[29]. It gives useful information on internal quality of fruits as it measures the bulk properties, not the superficial characteristics alone. The absorption is determined

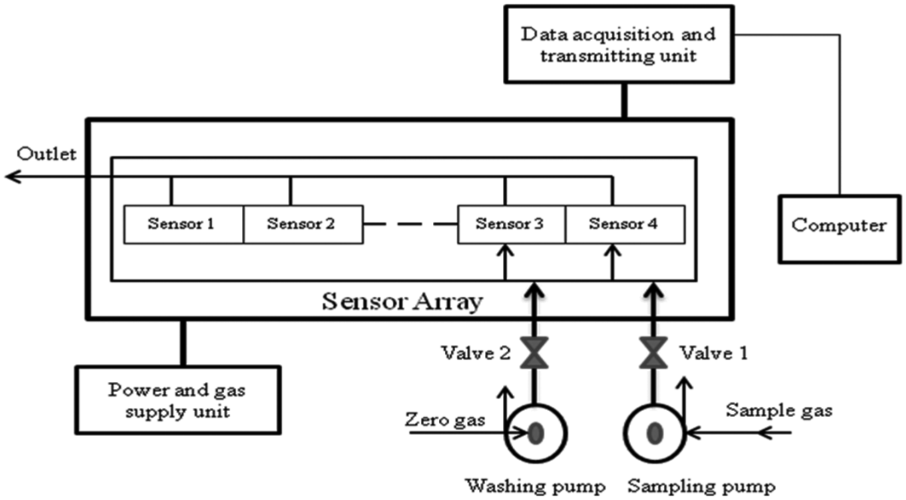
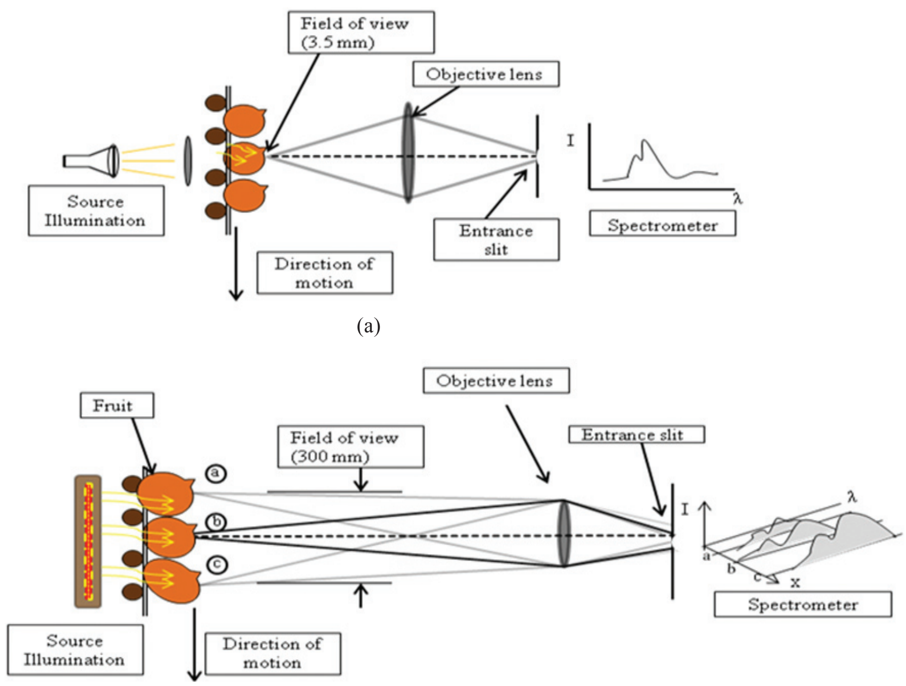


Figure 2. Schematic diagram of an E-nose system.



(a)

(b)

Figure 3. Sequential points in a continuous NIR system: (a)Typical mono and (b) Multiple.

by constituents such as water, sugars or by pigments like chlorophyll and anthocyanins. This method is suitable for grading, maturity determination, and detecting internal defects and in predicting shelf-life. Maturity of fruits can be measured even if the fruit is covered by intense blush and it is an advantage of this method[23].

4. ELECTROMAGNETIC METHODS

Electromagnetic spectrum consists of radio wave, microwave, ultraviolet rays, visible light, infrared rays, X-rays and gamma rays[23].

4.1 Nuclear Magnetic Resonance Techniques

The nuclear magnetic resonance technique involves NMR spectroscopy, NMR relaxometry and magnetic resonance imaging (MRI). Principle involves the absorption of magnetic energy by the nuclei placed in an alternating magnetic field. The amount of energy absorbed by the nuclei is directly proportional to the number of protons present in a particular sample[30]. Water and oil content in a sample can be determined by using this technique[31-35]. MRI can provide high resolution images of internal structures of intact fruit but the speed of measurement is low[36-38]. Presence of other food constituents in the material affects the determination of water and oil[39]. The spatially located NMR signals are reduced by the ice crystals formed in food, and thus, helpful in the determination of freeze damage caused during freeze storage of fruits and vegetables. This method is also useful in the detection of pits in fruits and vegetables. This is advantageous over other methods as it is simple and spectra can be interpreted easily[40]. Hernandez-Sanchez[41], *et al.* has used MRI to differentiate healthy and freeze damaged oranges. Undamaged oranges produced high and homogeneous signal intensity. Whereas, freeze injured oranges exhibited low intensity-signals. Freeze damage was confirmed by visual inspection.

5. DYNAMIC METHODS

5.1 X-ray

X-ray falls between gamma rays and ultraviolet rays. It covers the wavelength range of 0.01-10 nm. Maturity and various internal defects in fruits can be analysed by using this technique. Physiological defects in the tissues viz. freeze damage or internal browning or presence of pits, presence of foreign particles, infested fruits, etc. exhibit changes in density and water content. Thus, substandard fruits can be easily distinguished from healthy fruits. X-ray radiography and x-ray computed tomography (CT scanning) are widely used methods. X-ray radiography produces 2-dimensional (2D) images whereas x-ray computed tomography produces 3-dimensional images (3D)[42]. Yang[43], *et al.* has examined the internal injuries caused by insects such as *Bactrocera dorsalis* at various time intervals using X-ray imaging. Apple, pear, peach, cherry tomato and orange were the fruits selected for the study. The tunnels formed by the insects were detected successfully.

5.2 Ultrasonic

Ultrasonic waves correlate with the fruit firmness and are used to monitor fruit maturity. Surface wave transmission techniques are the most successful method of analysing fruits and vegetables using ultrasound. The principle involves the energy transmission into fruits and evaluation of response energy[3]. Morrison & Abeyratne[44] have studied the density, moisture content and firmness of ultrasonic waves of oranges successfully.

5.3 Acoustic Impulse Response Method

Acoustic impulse response method is used to analyse the texture of fruits[45-46]. The acoustic impulse resonance frequency (AIF) technique uses the natural frequencies of the intact fruit obtained by recording the sound, which is produced by hitting the fruit and then performing a Fourier transformation on the signal. For spherical fruit a stiffness factor can be calculated using the frequency and mass of the fruit. This method involves measurement of resonance frequency produced by fruits and resonance frequency of fruits change with ripening. The impact response produced by the fruit on applying force is calculated and is used to assess the internal quality and maturity of fruits[4]. The results are sensitive and depend on various features such as the shape of the fruit, impact angle, variations in fruit location. The results have been found to be mostly affected by water content of the fruit[23]. This technique provides useful information on fruit quality in shelf life studies but is not satisfactory for measuring the texture of fruit on tree[47-48].

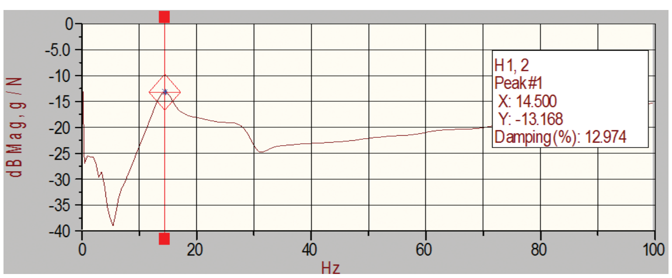


Figure 4. A typical acoustic spectrum with the help of acoustic impulse instrument.

5.4 Electrical Conductivity Measurement

This method includes electrical impedance spectroscopy (EIS) and dielectric analysis (DEA). The physical state of a material is measured as a function of frequency in EIS and the frequency ranges from 100 Hz - 10 MHz. It is simple and easier technique used to estimate the physiological status of various biological tissues[49-52]. Experimental frequency response of impedance is characterised by electrical equivalent circuits of materials. The physical properties of materials can be quantified by monitoring the changes in parameters at the equivalent circuit, among various equivalent models proposed[53-54]. DEA measurement is used in high frequency areas, generally 100 MHz - 10 GHz. DEA is used in moisture estimation and bulk density determination[55-60].

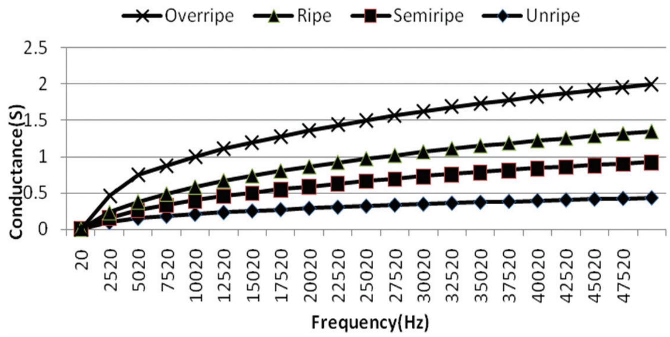


Figure 5. Electrical conductivity of banana at different ripening stages with the help of electrical conductivity monitoring equipment.

6. CONCLUSIONS

Non-destructive methods/techniques (NDT) measure the physical properties of fruits and vegetables; and correlate with the desired quality factors (dry matter, sugar content, water content, fat content, pigment concentration, etc.) by using various data analysis methods. Non-destructive methods facilitate the grading of fruits and vegetables based on their size, shape, maturity or ripeness. It is useful in the detection of external (deformation, discolouration) as well as internal defects (internal browning, internal bruises, freeze damage, presence of insects in the core, etc.). It is useful in the evaluation of both unprocessed and processed fruits and vegetables. Non-destructive methods can be used in fields to measure the fruit maturity on trees; in laboratories for sampling purpose and also in industries such as fruit processing, packaging and ware houses for continuous quality monitoring by adopting online systems. It is rapid, precise, reduces the processing time, reduces cost, save energy, improve the shelf life and quality. Hence, it is advantageous over destructive methods.

Imaging techniques such as MRI and X-ray are useful in the inspection of internal quality but do not provide details about the composition. NIR helps in assessing composition but do not provide image of internal physical parameters, whereas, spectrophotometric methods are helpful in measuring the fruit maturity or ripening stage. The maturity or ripeness is evaluated depending on the concentration of particular pigment (chlorophyll, anthocyanins, carotenoids etc.) present in the sample. Non-destructive methods are not suitable to measure all the chemical and physical quality parameters. High cost of equipments used and usage of different instruments to analyse different parameters are the major disadvantages of non-destructive methods.

REFERENCES

1. Abbott, J.A. Quality measurement of fruits and vegetables. *J. Postharvest Biol. Technol.*, 1999, **15**, 207-225. doi: 10.1016/S0925-5214(98)00086-6
2. Moreda, G.P.; Ortiz-Canavate, J.; Garcia-Ramos, F.J. & Ruiz-Altisent, M. Nondestructive technologies for fruit and vegetable size determination- A review. *J. Food Eng.*, 2009, **92**, 119-136. doi: 10.1016/j.jfoodeng.2008.11.004

3. Mirzaee, E.; Rafiee, S.; Keyhani, A. & EmamDjom-eh, Z. Physical properties of apricot to characterize best post harvesting options. *Aust. J. Crop. Sci*., 2010, **3**, 95-100.
4. Khalifa, S.; Komarizadeh, M.H. & Tousi, B. Usage of fruit response to both force and forced vibration applied to assess fruit firmness- a review. *AJCS*, 2011, **5**, 516-522.
5. Jha, S.N. & Kachru, R.P. Physical and aerodynamic ties of makhana. *J. Food Process. Eng.,* 1998, **79**, 301-316. doi: 10.1111/j.1745-4530.1998.tb00455.x
6. Jha, S.N. & Prasad, S. Physical and thermal properties of gorgon nut. *J. Food Process Eng*., 1993, **16**, 237-245. doi: 10.1111/j.1745-4530.1993.tb00319.x
7. Jha, S.N. Physical and hygroscopic properties of Makhana. *J. Agri. Eng. Res*., 1999, **72**, 145-150. doi: 10.1006/jaer.1998.0356
8. Gomez, A.H.; Pereira, A.G.; Jun, W. & Yong, H. Acoustic testing for fruit ripeness evaluation during peach storage stage. *Revista Ciencias Tecnicas Agropecuarias*, 2005, **14**, 28-33.
9. Luchsinger, L.E. & Walsh, C.S. Development of an objective and non destructive harvest maturity index for peaches and nectarines. *Acta Hort*., 1998, **465**, 679-687. doi: 10.17660/ActaHortic.1998.465.85
10. Jha, S.N. & Matsuoka, T. Review- Non-Destructive Techniques for Quality Evaluation of Intact Fruits and Vegetables. *Food Sci. Technol. Res.*, 2000, **6**, 248-251. doi: 10.3136/fstr.6.248
11. Sheeja, P.S. & Ajay Gokul,.A.J. Nondestructive quality evaluation for fruits and vegetables. *Int. J. Modern Trends Eng. Res.*, 2016, **3**, 2349-9745.
12. Roohinejad, S.H.; Mirhosseini, H.; Saari, N.; Mustafa, S.H.; Alias, I.; MeorHussin, A.S.H.; Hamid, A. & Manap, M.Y. Evaluation of GABA, crude protein and amino acid composition from different varieties of Malaysian brown rice. *Aust. J. Crop. Sci*., 2009, **3**, 184-190.
13. Hertog, M.L.A.T.M.; Ben-Arie, R.; Roth, E. & Nicolai, B.M. Humidity and temperature effects on invasive and non-invasive firmness measures. *Postharvest Biol. Technol*., 2004, **33**, 79-91. doi: 10.1016/j.postharvbio.2004.01.005
14. Magness, J.R. & Taylor, G.F. An improved type of pressure tester for determination of fruit maturity. *USDA Agric. Circular*, 1925, **350**. doi: 10.5962/bhl.title.66090
15. Schomer, H.A. & Olsen, K.L. A mechanical thumb for determining firmness of apples. *J. Am. Soc. Hortic. Sci*., 1962, **81**, 61-66.
16. Mizrach, A.; Nahir, D. & Ronen, B. Mechanical Thumb sensor for fruit and vegetable sorting. *Trans. ASABE*, 1992, **35**, 247-250. doi: 10.13031/2013.28595
17. Mizrach, A.; Nahir, D. & Ronen, B. Fruit and vegetable sorting by their rigidity. *Trans. ASABE* , 1985, Paper No. 85-3028.
18. Gardner, J.W. Detection of vapours and odours from a multisensory array using pattern recognition: principal component and cluster analysis. *Sens. Actuat*, 1991, **4**, 109-115. doi: 10.1016/0925-4005(91)80185-M
19. Freund, M.S. & Lewis, N.S. A chemically diverse conducting polymer-based electronic nose. *Proc. Natl. Acad. Sci*., 1995, **92**, 2652-2656. doi: 10.1073/pnas.92.7.2652
20. Abe, H.; Kanaya, S.; Takahashi, Y. & Sasaki, S.I. Extended studies of the automated odour sensing system based on plural semiconductor gas sensor with computerized pattern recognition techniques. *Anal. Chim. Acta*., 1988, **215**, 155-168. doi: 10.1016/S0003-2670(00)85275-7
21. Kowaiski, B.R. & Bender, C.F. Pattern recognition: a powerful approach to interpreting chemical data. *J. Amer. Chem. Soc.*, 1972, **94**, 5632-5639. doi: 10.1021/ja00771a016
22. Baldwin, E.A.; Bai, J.; Plotto, A & Dea, S. Electronic Noses and Tongues: Applications for the Food and Pharmaceutical Industries. *Sensors*, 2011, **11**, 4744-4766. doi: 10.3390/s110504744
23. Zerbini, P.E. Emerging technologies for Non-destructive quality evaluation of fruit. *J. Food and Ornamental Plant Research*, 2006, **14**, 13-23.
24. De Jager, A. & Roelofs, F.M.M. Prediction of optimum harvest date of Jonagold, in: De Jager, A.; Johnson, D.; Hohn, E. the postharvest treatment of fruit and vegetables-Current status and future prospects, Proceedings of the Sixth International Symposium of the European Concerted Action Program, COST, Luxembourg, 1996, **94**, 21-31.
25. Peng, Y. K. & Lu, R.F. Prediction of apple fruit firmness and soluble solids content using characteristics of multispectral scattering images. *J. Food Eng*., 2007, **82**, 142-152. doi: 10.1016/j.jfoodeng.2006.12.027
26. Qing, Z.S.; Ji, B.P. & Zude, M. Predicting soluble solid content and firmness in apple fruit by means of laser light backscattering image analysis. *J. Food Eng*., 2007, **82**, 58-67. doi: 10.1016/j.jfoodeng.2007.01.016
27. Peirs,A.; Schenk, A. & Nicolai, B.M. Effect of natural variability among apples on the accuracy of VIS-NIR caliberation models for optimal harvest date predictions. *J. Postharvest Biol. Technol*., 2005, **35**, 1-13. doi: 10.1016/j.postharvbio.2004.05.010
28. Yodh, A. & Chance, B. Spectroscopy and imaging with diffusing light. *Phys. Today*, 1995, **48**, 34-40. doi: 10.1063/1.881445
29. Cubeddu, R.; Pifferi, A.; Taroni, P.; Torricelli, A.; Valentini, G.; Ruiz-Altisent, M.; Valero, C. & Ortiz, C. Non-destructive measurements of the optical properties of fruits by means of time-resolved reflectance. In: B. Chance, R.; R. Alfano and B.J. Tromberg (eds), Optical Tomography and spectroscopy of Tissue, III. SPIE Press, Bellingham, 1999, **3597**, 445-449. doi: 10.1117/12.356839
30. Farrar, T.C. & Becker, E.D. Pulse and Fourier Transform NMR: Introduction to Theory and Methods. 1971,

Academic Press, New York.

31. Mousseri, J.; Steinberg, M.P.; Nelson, A.I. & Wei, L.S. Bound water capacity of corn starch and its derivatives by NMR. *J. Food Sci*., 1974, **39**, 114-116. doi: 10.1111/j.1365-2621.1974.tb01001.x
32. Leung, H.K.; Steinberg, M.P.; Wei, L.S. & Nelson, A.I. Water binding of macromolecules determined by pulsed NMR. *J. Food Sci*., 1976, **41**, 297-300. doi: 10.1111/j.1365-2621.1976.tb00604.x
33. Miller, B.S.; Lee, M.S.; Hughes, J.W. & Pomernz, Y. Measuring high moisture content of cereal grains by pulsed nuclear magnetic resonance. *Cereal Chem*., 1980, **57**, 126-129.
34. Brosio, E.F.; Conti, C.L. & Sykara, S. Moisture determination in starch-rich food products by pulsed nuclear magnetic resonance. *J. Food Technol*., 1978, **13**, 107-116. doi: 10.1111/j.1365-2621.1978.tb00784.x
35. Rollwitz, W.L. & Persyn, G.A. On-stream NMR measurements and control. *Am. Oil Chem. Soc. J*., 1971, **48**, 59-66.
36. Wang, C.Y. & Wang, P.C. Nondestructive detectuion of core breakdown in 'Bartlett' pears with nuclear magnetic resonance imaging. *Hort. Science*, 1989, **24**, 106-109.
37. Clark, C.J.; Hockings, P.D.; Joyce, D.C. & Mazucco, R.A. Application of magnetic resonance imaging to pre- and post-harvest studies of fruits and vegetables. *Postharvest Boil. Technol*., 1997, **11**, 1-21.
38. Clark, C.J. & Burmeister, D.M. Magnetic resonance imaging of browning development in 'Braeburn' apple during controlled- atmosphere storage under hogh CO2. *Hort. Sci*., 1999, **34**, 915-919.
39. Steinberg, M.P. & Richardson, S.J. Application of nucler magnetic resonance. Paper No. 11. Presented at the International Union Food Science and Technology Symposium on Water Activity. Theory and Application. 1986, June 13-14, Dallas, TX.
40. Ignat, I.; Volf, I. & Popa, V.I. A critical review on methods of characterisation of polyphenolic compounds in fruits and vegetables. *Food Chemistry*, 2011, **126**, 1821-1835. doi: 10.1016/j.foodchem.2010.12.026
41. Hernandez-Sanchez, N.; Barreiro, P.; Ruiz-Altisenta, M.; Ruiz-Cabello, J.& Fernandez- Valle, M.E. Detection of freeze injury in oranges by magnetic resonance imaging of moving samples. *Applied Magnetic Resonance*, 2004, **26**, 431-445. doi: 10.1007/BF03166814
42. Ruiz-Altisenta, M.; Ruiz-Garciaa, L.; Moredaa, G.P.; Renfu Lub, N.; Hernandez-Sancheza, N.; Correaa, E.C.; Diezmaa, B.; Nicolaic, B. & Garcia-Ramosd, J. Sensors for product characterisation and quality of specialty crops- A review. *Computers and Electronics in agriculture*, 2010, **74**, 176-194. doi: 10.1016/j.compag.2010.07.002
43. Yang, E.; Yang, M.; Liao, L. & Wu, W. Non-destructive quarantine technique- potential application of using X-ray images to detect early infestations caused by Oriental fruit fly (*Bactrocera dorsalis)* (Diptera: Tephritidae) in fruit. *Formosan Entomol*, 2006, **26**, 171-186.
44. Morrison, D.S. & Abeyratne, U.R. Ultrasonic technique for non-destructive quality evaluation of oranges. *J. Food Eng*., 2014. doi: 10.1016/j.jfoodeng.2014.05.018
45. Abbott, J.A.; Lu, R.; Upchurch, B.L. & Stroshine, R.L. Technologies for non destructive quality evaluation of fruit and vegetables. *Hort. Rev.*, 1997, **20**, 1-120.
46. Muramatsu, N.; Sakurai, N.; Yamamoto, R.; Nevis, D.J.; Takahara, T. & Ogata, T. Comparision of a non-destructive acoustic method for firmness measurement of kiwifruit. *Postharv. Biol. Technol*., 1997, **12**, 221-228. doi: 10.1016/S0925-5214(97)00054-9
47. Huarng, L.; Chen, P. & Upadhyaya, S. Determination of acoustic vibration modes in apples. *Trans. ASAE*, 1993, **36**, 1423-1429. doi: 10.13031/2013.28481
48. Landahl, S. & De Baerdemaeker, J. Dependence of stiffness measured with the acoustic impulse response technique on state of development of apples. In: Proceedings of the 6th International Symposium on Fruit, Nut and Vegetable Production Engineering, 2002, (pp. 475-480). ISBN 3-00-008305-7, Institutfu¯r Agrartechnik Bornime V., Potsdam-Bornim, Germany.
49. Ando, Y.; Mizutani, K. & Wakatsuki, N. Electrical impedance analysis of potato tissues during drying process. *J. Food Eng*., 2014, **121**, 24-31. doi: 10.1016/j.jfoodeng.2013.08.008
50. Damez, J.L.; Clerjon, S.; Abouelkaram, S. & Lepetit, J. Dielectric behaviour of beef meat in the1-1500 kHz range: simulation with the Fricker/Cole-Cole model. *Meat Science*, 2007, **77**, 512-519. doi: 10.1016/j.meatsci.2007.04.028
51. Greenham, C.G. Bruise and pressure injury in apple fruits. *J. Experimental Botany*, 1966, **17**, 404-409. doi: 10.1093/jxb/17.2.404
52. Yamamoto, T. & Yamamoto, Y. Electrical properties of the epidermal stratum. *Medical & Biological Engineering*, 1976, **14**, 151-158. doi: 10.1007/BF02478741
53. Yamamoto, T. & Yamamoto, Y. Analysis for the change of skin impedance. *Medical & Biological Engineering, & Computing*, 1977, **15**, 219-227. doi: 10.1007/BF02441041
54. Zhang, M.I.N. & Willison, J.H.M. Electrical impedance analysis in plant tissues: a double shell model. *Journal of Experimental Botany*, 1991, **42**, 1465-1475. doi: 10.1093/jxb/42.11.1465
55. Jha, S.N.; Narsaiah, K.; Basediya, A.L.; Sharma, R.; Jaiswal, P.; Kumar, R. & Bhardwaj, R. Measurement techniques and application of electrical properties for non destructive quality evaluation of foods- a review. *J. Food Science Technology*, 2011, **48**, 387-411. doi: 10.1007/s13197-011-0263-x
56. McKeown, M.S.; Trabelsi, S.; Tollner, E.W, & Nelson, S.O. Dielectric spectroscopy measurements for moisture prediction in Vidalia onions. *J. Food Eng.*, 2012, **111**, 505-510.

doi: 10.1016/j.jfoodeng.2012.02.034

57. Nelson, S.O. Measurement of microwave dielectric properties of particulate materials. J. *Food Eng.*, 1994, **21**, 365-384.
doi: 10.1016/0260-8774(94)90080-9
58. Nelson, S.O. Dielectric spectroscopy in agriculture. *J. Non-Crystalline Solids*, 2005, **351**, 2940-2944.
doi: 10.1016/j.jnoncrysol.2005.04.081
59. Trabelsi, S. & Nelson, S.O. Nondestructive sensing of bulk density and moisture content in shelled peanuts from microwave permittivity measurements. *Food Control*, 2006, **17**, 304-311.
doi: 10.1016/j.foodcont.2004.11.004
60. Kandala, C.V.; Nelson, S.O. & Lawrence, K.C. Non-destructive electrical measurement of moisture content in single kernels of corn. *J. Agricultural Eng. Res.*, 1989, **44**, 125-132.
doi: 10.1016/S0021-8634(89)80076-9
61. Petrisor, C.; Lucian radu, G.; Balan, V. & Campeanu, G. Rapid and non-destructive analytical techniques for measurement of apricot quality. *Romanian Biotechnol. Lett.*, 2010, **15**, 5213-5216.
62. Chauhan, O.P.; Chitravati, K. & Raju, P.S. New innovations in postharvest handling of fruits and vegetables. Paper presented at 2nd National Seminar on Hitech Horticulture: Challenges and Opportunities, Babasaheb Bhimrao Ambedkar University, Lucknow, India, 2015, 188-192.
63. Zude, M.; Herold, B.; Roger, J.; Bellon-Maurel, V. & Landahl, S. Non-destructive tests on the prediction of apple fruit flesh firmness and soluble solids content on tree and in shelf life. *J. Food Eng*, 2006, **77**, 254-260.
doi: 10.1016/j.jfoodeng.2005.06.027
64. Kuckenberg, J.; Tartachnyk, I. & Noga, G. Evaluation of fluorescence & re-emission techniques for monitoring changes in peel chlorophyll & internal fruit characteristics in sunlit & shaded sides of apple fruit during shelf-life. *J. Postharvest Biol. Technol.*, 2008, **48,** 231- 241.
doi: 10.1016/j.postharvbio.2007.10.013
65. Pathange, L. P.; Mallikarjuna, P.; Marini, R. P.; O'Keefe, S. &Vaughan, D. Non-destructive evaluation of apple maturity using an electronic nose system. *J. Food Eng.*, 2006, **77**, 1018-1023.
doi: 10.1016/j.jfoodeng.2005.08.034
66. Zude, M. Non-destructive prediction of banana fruit quality using VIS/NIR spectroscopy. *Fruits*, 2003, **58**, 135-142.
doi: 10.1051/fruits:2003001
67. Verlinden, B.E.; De Smedt, V. & Nicolai, B.M. Evaluation of ultrasonic wave propagation to measure chilling injury in tomatoes. *J. Postharvest Biol. Technol.*, 2004, **32**, 109-113.
doi: 10.1016/j.postharvbio.2003.11.006
68. Liu, Y.; Sun, X. & Ouyang, A. Nondestructive measurement of soluble solid content of navel orange fruit by visible-NIR spectrometric technique with PLSR and PCA- BPNN. *J. Food Eng*., 2008, **85**, 652-631.
69. Gomez, A.H.; Wang, J.; Hu, G. & Pereira, A.G. Monitoring storage shelf life of tomato using electronic nose technique. *J. Food Eng.*, 2008, **85**, 625-631.
doi: 10.1016/j.jfoodeng.2007.06.039
70. Guohua, H.; Yuling, W.; Dandan, Y.; Wenwen, D.; Linshan, Z. & Lvye, W. Study of peach freshness predictive method based on electronic nose. *J. Food Control*, 2012, **28**, 25-32.
doi: 10.1016/j.foodcont.2012.04.025

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