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REVIEW ARTICLE

Non-destructive quality evaluation by sensing maturity and ripening of fruits and vegetables

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ABSTRACT

Maturity at harvest is the most important factor determining its postharvest quality and storage potential of fresh fruits and vegetables. Ripening is the process by which fruit attained desirable flavour, quality, colour and other textural properties. The characterization of fruit and vegetables has been an important issue in the automatic sorting of fruits from the harvest site as well as from the cold storage. Characterization technique for horticultural crops is divided into two groups, i.e. non-destructive and destructive technique. For commercial scale packaging and other quality determination, non-destructive methods are useful as it govern essential quality parameters without any physical damage of produce. It works on the principle of optical properties, sonic vibration, machine vision technique, nuclear magnetic resonance (NMR), electronic noses, X-rays and computed tomography. Electronic nose technology sense aroma of fruit non-destructively, which can be used to determine fruit ripening stages after harvesting. Some of these techniques are used at large scale, but some are used only at laboratory level. These methods for evaluating maturity and ripening needs more initial investment.

Keywords: Non-destructive technique, ripening, maturity, fruits and vegetables

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INTRODUCTION

Nowadays, people become more conscious towards health and select produce for daily consumption based on their quality. They give more attention towards visual appeal, sensory quality, nutritional composition and health promoting bioactive compounds of fruits and vegetables. There are a number of compounds present in fruit and vegetable that possesses antioxidant property like anthocyanins, phenolics, flavonoids, vitamins (A, C, E) and prevents the onset of several chronic degenerative diseases. Due to rich source of vitamins and minerals, fruits and vegetables are also termed as protective food. Several methods are used commercially for quality evaluation of harvested fruits and vegetables. However, evaluation of interior quality of fruits and vegetables is most important to determine its postharvest life (Khalifa et al., 2011). Among the various quality factors, colour and firmness are important for growers as well as for processors as they affect produce appearance and consumer acceptability (Gomez et al., 2005; Luchsinger and Walsh, 1998). Therefore, appropriate techniques should be adopted for sorting, grading, packaging and quality evaluation of produce. Manually it is costly, labour intensive and difficult to analyse the quality factors like colour, texture, flavour and other quality attributes.

Quality of produce for consumption purpose depends upon the maturity and/or ripening stages of produce. There are mainly two methods for determining the quality attributes of horticultural produce namely destructive and non-destructive methods.

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Several new technologies, mathematical models have been developed to judge maturity or ripening of horticultural produce. The process of maturity is highly complex and synchronized process; require expression of several genes (Cherian et al., 2014). Non-destructive methods are rapid and efficient method for evaluating internal and external quality of horticultural produce, without causing damage to it.

Maturity and ripening

The words 'mature' and 'ripe' are generally synonymous in case of non-climacteric fruits i.e. they ripen only on the plants itself. However in case of climacteric fruits, mature fruit require a period before attaining a desirable stage of edible quality. Maturity is the stage at which a commodity reaches sufficient stage of development that after harvesting and postharvest handling its quality will be minimum acceptable to the consumer. Physiological maturity means the plant or plant part completes the development process but it may or may not ripe. Fruits like mango, apple, banana etc. are generally harvested at this maturity stage. Seeds of any fruit and vegetable crops can germinate only after completing physiological maturity stages, after that it start senescence. In horticultural maturity, produce possess pre-requisites for utilization by the consumers for a particular purpose (Kader, 1999). Vegetables like okra, beans, onions, all gourds are harvested at this maturity stage.

Ripening is the process in which several catabolic and anabolic process take place due to an array of several enzymatic activity thereby, physiologically mature inedible plant part converted to edible one. Fruits are classified into two group *viz*. climacteric and non-climacteric, based on their ripening behaviour. Climacteric fruits continue their ontogeny even after harvest i.e. it ripens on or off the mother plant after attaining certain maturity stage e.g. mango, banana, papaya etc. These fruits release ethylene along with increased rate of respiration during the ripening process. Non-climacteric fruit does not ripen, once detached from the mother plant, e.g. grape, citrus, litchi etc.

Non-Destructive Technology (NDT)

In this technique, quality of fruits is determined without damaging or destroying them. The different non-destructive techniques (NDT) and sensors used for various quality assessment are magnetic resonance imaging (MRI), X-ray computed tomography (CT), machine vision technique, electrical properties detection, near-infrared (NIR) spectroscopy, Raman spectroscopy, DA meter, electronic nose techniques etc.

Machine vision technique

Earlier machine vision technique was used in agriculture to specify plant species. With the advancement of image processing technology, computer software and hardware, machine vision systems are used for auto quality detection and grading of fruits. In USA, black and white image processing technology is being used to determine surface bruise in apples (Gao et al., 2014).

X-ray and Computer tomography (CT)

Initially, X-ray and CT were developed as a tool for producing rapid non-destructive, high contrast representative medical images. After that, it has been adapted and spread for use in a wide area including fruit industry. It can be used to take picture of the produce interior in 2D and 3D based on the principle of attenuation of an electromagnetic wave. Generally, X-ray CT scanners consist of three common parts: an X-ray source, a sample manipulation stage and a detector (Li et al., 2016).

Magnetic Resonance Imaging (MRI)

It comes under nuclear magnetic resonance (NMR) technique that also includes NMR spectroscopy and NMR relaxometry (Lakshmi et al., 2017). Magnetic resonance imaging gives a high resolution image of inside of produce in two or three dimensions (Wang and Wang, 1989; Clark et al., 1997; Clark and Burmeister, 1999).

Near-Infrared (NIR) Spectroscopy

This method is examined for evaluating firmness, freshness, acidity, TSS, and other characteristics of different fruits since 1980s. It is suitable and appropriate method for judging these parameters (Cho, 1996; Kawano, 1999). It works based on the colour intensity of the sample. It uses interaction of atom or molecule and electromagnetic radiation for qualitative as well as quantitative physico-chemical information. They absorb and/or reflect light intensity that passes through colour pigment within the range of ultraviolet and visible range of electromagnetic spectrum depending on their energy content. Colour intensity indicates the physiological stage of leaf or fruit.

Optical properties

Reflectance, transmittance, absorbance, fluorescence and/or scattering of light governed the optical properties of fruits and vegetables. It has different absorption and reflection properties in the light of different ray, due to compositional differences of the produce. Internal quality systems and detecting principle of produce are based on three different measuring methods, *viz*. regular reflection, transmittance and diffuse reflection (Ying et al., 2004). Total soluble solids content, acidity, sugar, starch and overall maturity of fruits can be assessed non-destructively by using spectral-optical methods (Lakshmi et al., 2017).

Delta Absorbance (DA) meter

The DA meter is a handheld instrument measuring green pigment in fruit. It works mainly as electronic colour chart by taking index of absorption differences (I_{AD}) within the range of 670 to 720 nm wavelengths (Doerflinger et al., 2016). Chlorophyll content in fruit skin is strongly and positively related to I_{AD} value. These values decline significantly at the time of maturity and negatively related to harvest period (DeLong et al., 2016).

Application in different horticultural produce

Volatile organic compounds produced during ripening, measured by zNose^{TM}, which could be used to determine mango fruit maturity to harvest the fruit at appropriate stage of maturity (Nouri et al., 2014). Capacitance measurement in papaya by means of voltage difference is a good non-destructive method to evaluate ripening stage and firmness. They reported that ripening stage is inversely proportional to firmness, voltage change and natural frequency of papaya fruit (Bhosale and Sundaram, 2015). Cherry-Meter measures an Index of Absorbance Difference (I_{AD}), which showed high correlation with fruit quality parameters. It showed positive but differential correlations between I_{AD} values and fruit anthocyanin in highbush blueberry (*Vaccinium corymbosum* L.) cultivars Misty and Sharpblue, which was higher for Misty (r = 0.970) than for Sharpblue (r = 0.714). I_{AD} values also correlate significantly with fruit fresh weight (0.447 for Sharpblue and 0.559 for Misty) (Ribera-Fonseca et al., 2016). Capacitive sensing system was designed and developed to measure ripening in banana fruit. In this method, fruit is placed in the capacitive sensor as a dielectric material and then the capacitance of sensor was measured at 10 kHz to 10 MHz sinusoidal frequencies. Ripeness of fruit of uniform size was directly proportional to capacitance across the fruit (Sankhe, 2015). Non-destructive instrument, DA meter provides a reading of difference in absorbance (I_{AD}). The I_{AD} estimates chlorophyll a concentration based on absorbance differences between 670 and 720 nm. After giving different application of ReTain and harvista (fruit ripening modulater) in 'Empire' apple, Doerflinger et al. (2016) measured maturity parameters namely, I_{AD}, internal ethylene concentration (IEC), firmness and starch pattern index. They found weak correlations between individual fruits and harvest indices, but stronger relationship after combining the data and ranked by I_{AD} readings. Different non-destructive methods and quality parameters that can be determined were given in Table 1.

Table1. Non-destructive methods for quality determination of fruits

Method	Technique	Parameters
Optics	Image analysis, reflectance, transmittance and absorbance spectroscopy, laser spectroscopy	Size, shape, colour, external defect, internal component, visco-elasticity, firmness
X-ray	X-ray image and CT	Internal cavity and structure, ripeness
UV-ray	UV-ray, Spectroscopy	Carotenoids, anthocyanin contents
NIR	Reflectance, transmittance, interactance and transflectance	Internal component
Mechanics	Ultrasonic	Internal cavity and structure, ripeness
	Sonic	Internal cavity and structure, firmness, ripeness
		Visco-elasticity, firmness, ripeness
	Vibrated excitation	Maturity, oil and sugar content
	Ultrasound	
Machine vision technique	Image processing technology, computer software and hardware	Surface colour, ratio of total soluble solid to titratable acidity
Electromagnetic	Impedence	Moisture content, density, sugar content, internal cavity
	MR/MRI	Density, sugar content, moisture content, oil content, internal defect and structure

Jamaludin et al. (2014) used dielectric based system for judging ripening stages in banana. They observed increase in impedance value with ripening stages at certain frequency. It easily separated ripe, unripe and overripe fruits in the frequency range between 20.1 kHz to 30.1 kHz. Qin et al. (2012) used spatially offset raman spectroscopy (SORS) for non-destructive evaluation of internal maturity of tomatoes. They included seven ripening stages (immature green, mature green, breaker, turning, pink, light red, and red) and found that spectral information divergence (SID) with reference to pure lycopene value decreased as the tomato fruit ripened, and thus these values can be used for analysing the internal ripeness of tomato. Martínez (2013) worked on eggplant (*Solanum melongena* L. cv. Traviata) to examine physical quality attributes by non-destructive compression tests and hyperspectral imaging. They found that surface stiffness and peel gloss decreased whereas density increased significantly over time during postharvest storage. Freshness index of eggplant was defined as the product of surface stiffness and peel gloss ratios divided by the density ratio. It showed best model as a function of surface stiffness loss with highest correlation coefficient (0.99) and the lowest mean square values (0.0014). Freshness index gave less efficient predictor as a function of peel gloss loss.

CONCLUSION

Non-destructive technology uses optical property, sonic vibration, machine vision technique, nuclear magnetic resonance etc. for fruit quality detection. This method of sensing maturity and ripening is easy, efficient and beneficial to judge maturity and ripening of fruit without harming them. Ripeness is directly proportional to I_{AD} and capacitance across the fruit. At advanced maturity stages, Cherry-Meter was able to discriminate different maturity levels. NIR spectroscopy is used to assess TSS for thin skin fruits (apricot) whereas, X-ray CT with stronger penetrating power is used for thick skin fruit (watermelon). Sonic properties, NMR detection technique are still in laboratory experiment, not for commercial purpose. However, these methods for evaluating maturity and ripening require more initial investment and also need further work.

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