Nondestructive quality assessment of Agro-food products

Mohammad Aboonajmi, Hamideh Faridi
Department of Agrotechnology, College of Abouraihan, University of Tehran, Tehran, Iran
email address: abonajmi@ut.ac.ir

Abstract

The quality and safety of agro-food products is a growing concern nowadays. Nondestructive attributed quality assessment methods have gained dominant factor and considerable attempts for fresh fruit and vegetable these years. This review covers development in the field of non-destructive techniques for assessment internal quality of agro-food products up to now. In this review advanced sensing methods such as optical, spectroscopic, acoustic, mechanical and other technique like E-nose and E-tongue and so on are discussed. Much research is now being directed toward the development of nondestructive measurement devices that are versatile, economical, and simple to use. Emphases are placed on those method have shown great advantage for agro-food products. As sensor measure a single quality property, Sensor fusion technique has shown great potential for overall attributed quality measurement. It is possible to screen large numbers of diverse samples by applying these techniques.

Keywords: Quality, Nondestructive, Sensor, Agro-food products

1. Introduction

Nondestructive testing equipment can be widely used throughout the food industry. Raw material control in the field or at the factory reception, process control either online or off-line after sampling, rapid analysis of intermediate or final products in the laboratory, product development and storage testing and research are the most relevant nondestructive testing areas.

In recent years, Iran achieved the first ranking in terms of production and business in the Middle East with annual production of close to twenty million tons of fruit. We need to develop and adopt advanced technologies in post-harvest in terms of growing demand for quality products and healthy. In this context, the acquisition of new knowledge in the field of non-destructive evaluation of the quality of agro-food products is extremely important. Today, measuring the quantity and quality of agricultural products without any injuries has a special position in post-harvesting and processing of agricultural products. In this regard, various non-destructive methods have been developed to detect internal properties of crops which many of them come to the practical application as used in the grading system. These methods are replacing traditional ones which were too expensive, unreliable, difficult and exhausting. On the other hand, the power of human visual perception is too limited because of the human narrow band of the electromagnetic spectrum which cause the human decision with errors and even impossible about identifying the quality factors such as flavor in agricultural products, the amount of nutrients, texture and internal injuries.

In a brief definition, the qualitative and quantitative measurements in agricultural products and processed food that has been surveyed without any physical, chemical, thermal and mechanical damages to cycle back is called non-destructive test. Diversity and abundance of the parameters and qualitative features of agro-products were the most reason of Non-destructive development methods in recent four decades with the growth of the technology of the accurate measuring instruments. Nondestructive tests should not be detrimental effects on the product and it should be in order to ensure customer satisfaction of products. Various non-destructive methods have been described in table 1.

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2. Spectroscopy Techniques

A. Visual Spectroscopy
Chemical components of any food material absorb light energy at specific wavelengths; hence some compositional information can be determined from spectra measured by spectrophotometers. In the visible wavelength range, pigments such as chlorophylls, carotenoids, anthocyanins and other coloured compounds are the major light absorbing component of foodstuffs such as vegetables [1]. The reflectance features of any object in the visible region (380–750 nm) are perceived by human eyes as colour, which prepare information about the pigment content of the sample [2]. When light is absorbed and some part of it is reflected by the target material, colours appear. If all light is reflected, the object will appear white, and if all is absorbed, it will appear black. The wavelengths influence the observed colour which therefore is related on both the light source and the absorption [3].

![Absorption spectra of chlorophyll and carotenoids. From www.cfb.unh.edu](image)

B. Near Infrared Spectroscopy

Near-infrared spectroscopy is one of the most widely studied quality assessment tools for the last twenty years. It is a rapid, powerful, reliable and non-destructive technique for the measuring qualitative and quantitative properties of biological materials [4, 5]. This technique is now increasingly used for non-destructive measurement of the quality of fruits and vegetables such as soluble solids (Brix), acidity, titratable acidity, water content, dry matter, firmness, and so on and for rapid assessment of fiber, protein, fat, ash content and so on [4,6]. Near-Infrared spectroscopy involves use of light in the wavelengths range of 780-2500 nm, and the light penetration depth, depends on the wavelength and the sample characteristics. It is up to 4 mm in the 700-900 nm range [7, 8]. In the NIR region, the absorption is due to overtones and the combination tones of the fundamental infrared (IR) vibration bands of bonds where the electric dipole moment changes; anharmonic bonds [9]. The light emitted from the object (sample), reveals information about chemical properties and surface structure. The light scattered from fresh produce reveals the microstructure of the tissue and the light absorption is associated with the presence of chemical components in the sample under study. Therefore both phenomenons are useful in quality assessment [8].

C. Microwave Dielectric Spectroscopy

Microwave electromagnetic radiation spectrum stretch from a frequency range 108 Hz to 1011Hz [10]. Microwave dielectric spectroscopy is an emerging technique used in assessment of the internal quality based on dielectric properties of food products [11]. Dielectric properties of all materials are dependent on their molecular structure. The dielectric properties of food materials in the microwave region can be determined by different microwave measuring sensors [12]. The specific method used depends on the frequency range and the type of target material. The water content and soluble solid content of watermelon were evaluated by measuring permittivity of watermelon [13]. The open ended probe was used to measure the complex permittivity of watermelon. Soluble solid content and moisture content of watermelon were used as a quality factor for the correlation with the dielectric properties. A high correlation was obtained between the dielectric constant and solid soluble content [13]. Nelson and Trabelsi [14] used the permittivity measurements of honeydew melons and watermelons, with an open-ended coaxial-line probe and impedance analyzer at frequencies of 10 MHz to 1.8 GHz to provide information about their maturity. Total soluble solid of melons was used as measure of maturity and was correlated with permittivity. Dielectric constant and loss factor correlations with total soluble solid were low, but a high correlation was recorded between the total soluble solid and permittivity from a complex-plane plot of dielectric constant and loss factor, each divided by total soluble solid.

Dielectric spectroscopy can be considered an important non-destructive tool for controlling the freezing process of potato at frequency range of 500 MHz to 20 GHz [15]. The dielectric properties of tomatoes were measured over a frequency...
range of 300–3000 MHz at temperatures between 22 and 120 °C [16]. The dielectric properties has been used to measure the moisture content and tissue density of agricultural materials by predicting heating rates which in turn describe the behavior of products when exposed to high-frequency or microwave electric fields [17].

D. X-Ray and Computerized Tomography (CT)

X-ray imaging is an established method for fast detecting the strongly attenuating materials. It has been applied to a number of inspection applications within the agricultural and food industries [18, 19]. Recently, techniques based on two-dimensional (2D) X-ray, and computed tomographic (CT) imaging have been explored, and used for internal quality determination of agricultural and food products non-destructively [20, 21]. Despite extensive research effort, real-time inspection systems for detection of internal quality of fresh produce are not commercially available, because of limitations in useful information when using high-speed systems [22]. X-ray is short wave radiation (0.01 – 10 nm) with high energy (1.92 × 10-17 – 1.92 × 10-14J) that can easily penetrate matter. X-rays are generated by bombarding electrons on a metallic anode (X-ray tube) [23]. Traditional CT is an imaging modality where an x-ray tube is rotated around an object or objects and the attenuation is recorded on a detector. Other equipment may contain a rotating stage in front of a fixed x-ray tube and detector [24]. Quenon and De Baerdemaeker [25] developed X-ray method to measure the length of the floral stalk in Belgian endive Cichorium intybus L non-destructively. Detection algorithm was developed based on the minimal transmitted intensities along the length. The method is very accurate with an absolute precision of 4.9mm and allows the study of the influence of storage conditions and time on the internal quality of Belgian endive. They concluded the X-ray transmission is suitable for a non-destructive measurement of the length of the floral stalk in Belgian endive.

3. Sound Waves Techniques

Acoustic sound waves (in the range of human hearing i.e 20 Hz to 20 KHz) and ultrasonic waves (which are above the range of human hearing i.e. 20 KHz to 1 MHz) are used to evaluate the quality of fresh vegetables non-destructively [26]. In acoustic sound, a device is often used to lightly tap or thump the commodity to create a sound wave that pass through the product tissue. The characteristics of the sound waves as they pass though the product can be used to indicate the quality attributes of fruit and vegetables during postharvest processes [22].

A. Acoustics

Acoustic resonance technique is an emerging trend for non-destructive quality evaluation of fruits and vegetables. This technique is based on the response to sound and vibration when the source is gently tapped. It can be used to predict the maturity, internal quality, ripening stage and other similar parameters using the audible frequency range of 20 Hz to 20 kHz. The availability of high-speed data acquisition and processing technology has renewed research interest in the development of impact and sonic response techniques [27]. Acoustic pulses are sent from a transducer to an object and then scattered, transmitted or reflected from the object. Because of the wide agro-food product diversity, there are much potential for applications of acoustic as a nondestructive technique. Quality assurance is crucial for monitoring and evaluating the final agricultural materials and food products to ensure their safety and to ensure that they meet consumer expectations with regard to organoleptic attributes and consistent quality [28-30]. Acoustic emission (AE) is an important attributed quality of food texture. Acoustic features of snack-type food are as important as fresh products. Crunchiness and crispness, which are noticed as signs of freshness, are other aspects of acoustic properties. Analyzing the crunchiness and crispness sound percept by a human ear is considered as the main physical index influencing the consumer’s evaluation of quality [30-32]. The disintegration of food procreates elastic waves that are used to identify the acoustic properties. Alteration of food texture can be measured by analysis of the emitted sound. Measuring the sound produced by manipulation of a food product can be performed by destructive and nondestructive tests (passive and active method). Acoustic methods are divided into methods of measuring sound emission, absorption and other methods of determining phase oscillation. All parameter changes are caused by the medium through which the wave is passing [33].
When an acoustic wave reaches to the agricultural products, the reflected or transmitted acoustic wave depends on the acoustic characteristics of the agricultural products. The reflected or transmitted acoustic wave can provide information on the interaction between acoustic wave and agricultural products, and acoustic characteristics such as attenuation coefficient, transmitting velocity, acoustic impedance, and natural frequency. Different agricultural products have various acoustic characteristics based on the internal tissue structures [34, 35].

B. Ultrasound

Ultrasound technology has been known and used in many areas, including medical diagnostics, industrial processes, and metal fabrication [36]. It has also gained attention and increasing popularity in assessment and testing the biological and food-stuffs [37]. The advantages of ultrasonic methods includes quick measurement and interpretation, penetrating optically opaque materials, accuracy, low cost, freedom from radiation hazards, and the ease of on-line measurement. At high frequencies and low power it can be used as an analytical and evaluation tool, and at a very high power it can assist processing [36]. Ultrasonic vibrations are above the audible frequency range >20 kHz. Ultrasound is generated by a transducer containing a ceramic crystal which is excited by a short electrical pulse that has a typical form of several sine cycles. Through the piezoelectric effect, this electrical energy is converted to a mechanical wave that is propagated as a short sonic pulse at the fundamental frequency of the transducer. The ultrasound signal emerging from the test sample is sensed by a piezoelectric element that acts as a receiver, converting any ultrasound impinging on it, back to electrical energy. Aboonajmi et al. applied an ultrasound method as a nondestructive means of evaluating freshness of commercial poultry egg during different storage condition. The decrease of phase velocity during storage was a good indices for egg freshness assessment [68]. Mizrach et al. reported that ultrasonic non-destructively measurement system was relied for the assessment of same transmission parameters which may be have quantitative relation with the ripening, maturity, firmness and other internal quality of fruit and vegetables [39].

Ultrasound techniques used with agro-foods form an entire field of applications, and provide the user with a wide variety of information about the properties of materials being processed [40]. For fruit and vegetable tissues, changes in these features form part of the natural processes that occur during growth and maturation, and in the course of the harvest period, storage and shelf-life. Various physiological and physiochemical changes occurred during these processes, and each transition is specifically evaluated by one or more factors, characteristic of the pre-harvest, harvest, and postharvest periods. The changes are expressed differently in the course of the various periods, and are mostly reflected in the quality of the final produce. Textural attributes are among the main factors considered in quality assessment [41], and are regularly used for determination of the stage of maturity of various kinds of fruit and vegetables [20]. Firmness is considered as one of the main indices of maturity and its changes during the ripening and softening process start on the tree and continue during harvesting, handling and storage. Chemical contents and concentration in fresh tissues are also important factors in determining maturity of fruit and vegetables, but firmness is the factor most closely related to the stage of maturity [41].

When acoustical measurements are used in conjunction with other physiochemical measurements, such as firmness, mealiness, dry weight percentage (DW), oil contents, total soluble solids (TSS), and acidity, a link between acoustical parameters and physiochemical indices enables the indirect assessment of the proper harvesting time, storage period or shelf-life [42, 20, 28]. The ultrasound technique has been accepted mainly for non-destructive, rapid, and accurate assessment of the changes involved, but has also been performed to monitor additional natural and environmental factors that cause changes in quality-related parameters [42-44].

The most important mechanical property of fruit and vegetable that correlates with ultrasound characteristics is firmness. It is a very important parameter, which reflects the changes in tissue texture during the course of growth, maturation, storage and shelf-life. The degree of firmness is usually associated with ripeness, freshness, retention of good quality and,
therefore, with saleability. It can be measured by compression or by puncturing with various probes, at a variety of force or deformation levels, depending in the purpose of the measurement and how the quality attributes are defined [20]. Horticulturists attend to define firmness as the maximum force applied, although sometimes the rupture or bio-yield force is used [20]. Penetration tests are the most acceptable method for measuring firmness. Firmness of fruit is commonly measured with destructive penetration devices equipped with a puncture probe, or a conical or curved head (e.g., John Chatillon & Sons, New York, USA). These techniques are generally destructive, not objective, and time consuming; therefore a rapid non-destructive technique has been sought. Ultrasound was found to be one of several techniques that correlated well with firmness, and was suggested as the basis of a method that could fulfill these requirements pre- and postharvest. In most cases described in this review, both destructive penetration measurements of firmness and ultrasound measurements were performed on the same sample of fruit in order to correlate the two techniques. Obviously, non-destructive ultrasound measurements were taken first. The non-destructive ultrasound measurements allowed correlations with firmness changes for a given fruit, and even in exactly the same measurement location during periods such as shelf-life and storage [44-45]. In most cases, firmness readings that were obtained with whole fruit were taken in the radial direction at a point on the circumference of the largest cross-section perpendicular to the blossom end-stem end axis [46].

Each kind of fruit has its own dominant physical parameters. In avocado fruit, oil, and dry weight content of the flesh are the subjects of the most acceptable methods for a reliable test of maturity, according to which the harvest date is determined [47]. The dry weight (DW) is usually determined according to Lee et al. [48]: samples taken from the fruit tissue for DW measurement are weighed and dried in an oven at 60 °C for 3 days and are then reweighed. The oil content of the avocado fruit is determined by means of long-established refractive index techniques [49-50] that have been described in detail by Lee [51]. Physiochemical indicators of maturity in mango during the ripening process are decreasing acidity and increasing contents of sugars, soluble solids and total solids in the flesh, and there is a concurrent reduction in titratable acidity [52].

4. Imaging Analysis Techniques
An imaging system technique is a common to obtain spatial information of the samples in monochromatic forms or colour images. Imaging system is therefore used for colour, shape, size, surface texture evaluation of food products and to detect surface defect in food samples, however it cannot identify or detects chemical properties of a food product [54, 55].

A. Hyperspectral Imaging
Hyperspectral imaging system has become a powerful tool and popular for food research. It can capture the spatial data of the whole target at selected wavelengths instead of measuring spectral values at single point [56]. It’s an inherently effective tool because of ability to collect data with both spatial and spectral characteristics of the scanned target [57]. Itoh et al. [58] used near-infrared hyper spectral imaging system to measure the nitrate concentration distribution in a vegetable leaf. The nitrate concentration estimated at each pixel in a leaf image with high accuracy, and the results indicated variation in nitrate concentration inside a leaf. Wang et al. [59] developed a NIR reflectance hyperspectral imaging system for sour skin detection in Vidalia onions. The system consisted of an InGaAs video camera, normal lens, liquid crystal tunable filter (LCTF), and frame grabber for acquiring image data, and two tungsten halogen lamps as light sources. The schematic diagram of the system for transmission experiments to take transmittance images of food material (sweet onions, onion bulbs), onion sample placed between the light source and the hyperspectral imaging system as shown in Figure 5 [59].

![Diagram of hyperspectral imaging system for an object transmittance experiments](image)

Figure 5. Schematic of hyperspectral imaging system for an object transmittance experiments

B. Machine vision

During recent years, the machine vision system has been increasingly used for examination of fruits and vegetables, especially for applications in quality inspection and defect sorting applications [60]. Computer vision system is recognized as the integration of devices for non-contact optical sensing, computing and decision processes, which receive and interpret automatically an image of a real scene [61]. It includes capturing, processing and analysis of two-dimensional images, with other noting that aims to duplicate the effect of human vision by electronically perceiving and understanding an image.

C. Magnetic resonance (MR) and magnetic resonance imaging (MRI)

Magnetic resonance imaging (MRI) has become a well-established technique for nondestructive analysis of the internal structure of food. The MRI technique provides a nondestructive method to evaluate both the qualitative and the quantitative properties of biological materials [62]. This technique is based on the interaction of certain nuclei, such as carbon and hydrogen, with electromagnetic radiation in the radio frequency range [63]. It is used to evaluate the property of interest for food processing (as drying), physical tissue damage assessment (as bruising) and others for online sorting process or detection of internal defects (as internal browning) [64]. Magnetic resonance imaging technique has been used as a non-invasive research tool for internal quality assessment of some fruit and vegetables [65].

5. Sensor fusion

Sensor fusion provide a collaborative a collaborative approached with multi sensors to improve the quality assessment of agro-food products for a high quality is attracting massive attention recently. Combining of data deriving from multi sensor system means more accurate, more complete or more dependable is better than these sources were used individually. An acoustic sensor, NIR spectrometer, E-nose (EN) and on line hyperspectral imaging combined for nondestructive evaluation of apple fruit (firmness and soluble solid content ,Fig-6). Sensor fusion technology has also been used for assessment juice (69), fruit (70-71), meat (72), fish (73), tea (74) and other agro-food products.
6. Conclusions

The current review focused on some valuable applications of non-destructive methods for Agro-food quality evaluation. Non-destructive techniques are center of attraction for its feasibility to predict external and internal quality of fruit without any loss in structure. Moreover, these techniques provide constitutional variation of the fruit/vegetable products and their accurate quantification, leading to better characterization and improved quality and safety evaluation results. Considering these advantages, it is expected that nondestructive technology will play more significant role in the field of vegetables/fruits industries in near future.

References


