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REVIEW PAPER

A Review of Non-destructive Methods for Quality Evaluation and Sorting of Agricultural Products

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A number of methods for quality evaluation and sorting of agricultural products have been developed by different researchers over the past three decades. These methods are based on the detection of various physical properties which correlate well with certain quality factors of the products. This paper presents an overview of various methods which are based on one of the following properties: density, firmness, vibrational characteristics, X-ray and gamma ray transmission, optical reflectance and transmission, electrical properties, and nuclear magnetic resonance, NMR. The sophistication of non-destructive methods has evolved rapidly with modern technologies. Optical methods which utilize high-speed optical detection and computerized data processing are the most successful methods which can provide high-speed quality evaluation and sorting of several products with a high degree of accuracy. The use of various modern image acquisition techniques, such as solid-state TV camera, line-scan camera, X-ray scanning, ultrasonic scanning, and NMR imaging, in conjunction with image processing techniques has provided new opportunities for researchers to develop many new and improved techniques for non-destructive quality evaluation of agricultural products.

1. Introduction

Qualitative evaluation of agricultural products has been a subject of interest to researchers for many years. However, there is no clear definition of quality for agricultural products; different researchers define quality differently. Nevertheless, certain basic factors are commonly used to characterize quality: size, shape, colour, flavour, texture, taste, and freedom from defects and foreign materials. Since many quality factors of agricultural products are related to physical properties of the products, it is often possible to develop non-destructive methods for evaluating quality based on physical properties. In the past 30 years researchers have developed such methods for a number of agricultural products. This paper presents an overview of these methods.

2. Physical properties

2.1. *Density*

The relationship between density and the quality of agricultural products has been recognized for more than a century. The density of many fruits and vegetables increases with maturity. On the other hand, certain types of damage and defects, such as frost damage in citrus, insect damage in fruits and grains, puffiness in tomatoes, bloaters in cucumbers, and hollow heart in potatoes, tend to reduce the density of the product.

Zaltzman *et al.*[1] presented a comprehensive literature review of previous studies related to quality evaluation of agricultural products based on density differences. The following are some of the common methods used: removing fruits that float in water or solutions of known density, dropping fruits into a moving stream of water in which low-density fruits will rise faster than high-density ones, and releasing fruits from the bottom of a flowing stream of water and skimming off fruits of different density ranges from the top of the water channel at different horizontal distances from the point of release.[2–4] A method that utilizes a fluidized bed medium for separating potatoes from clods and stones was studied extensively by Zaltzman and his co-workers.[5,6] They developed a pilot plant unit that can separate potatoes from clods and stones at a rate of 5 t/h with better than 99% potato recovery and 100% clod and stone removal.

2.2. *Firmness*

Firmness is a physical property that is often used for evaluating the quality of fruits and vegetables. In many agricultural products firmness is related to maturity. In general, firmness of fruits decreases gradually as they become more mature and decreases rapidly as they ripen. Overripe and damaged fruits become relatively soft. Thus, firmness can be used as a criterion for sorting agricultural products into different maturity groups or for separating overripe and damaged fruits from good ones. Several methods for measuring fruit firmness have been developed.

2.2.1. *Force-deformation*

Perry[7] developed a non-destructive firmness-testing unit that applied low-pressure air simultaneously to small areas on opposite sides of peaches to generate a non-bruising maturity-indicating deformation. Mehlschau *et al.*[8] developed a "deformeter" for non-destructive maturity detection for pears based on the measurement of deformation resulting from pressing two steel balls against the opposite sides of the fruit with a fixed force. Mizrach *et al.*[9] used a 3 mm diameter pin as a mechanical thumb to sense firmness of oranges and tomatoes.

2.2.2. *Impact force*

The force response of an elastic sphere impacting a rigid surface is governed by the impacting velocity, mass, radius of curvature, elastic modulus, and Poisson's ratio of the sphere. Researchers have found that the impact of a fruit on a rigid surface can be closely modelled by the impact of an elastic sphere and that the firmness of a fruit has a direct effect on the impact force response. Nahir *et al.*[10] reported that when tomatoes were dropped from a 70 mm height onto a rigid surface, the impact force response is highly correlated with fruit weight and fruit firmness. They subsequently developed an experimental tomato grading machine which, by measuring and analysing the impact force response of the fruit, can separate tomatoes on the basis of weight and colour. Delwiche *et al.*[11] analysed impact forces of peaches striking a rigid surface and found that certain impact force characteristics were highly correlated with the fruit's elastic modulus and penetrometer measurements of flesh firmness. A single lane firmness sorting system was developed which used the index F/t^2 (where F and t are the peak impact force and the time required to reach peak force, respectively) to sort peaches and pears into hard, firm, and soft categories.[12]

2.2.3. *Impact-rebound*

Bryan *et al.*[13] developed a method for separating damaged soft oranges from undamaged ones. The oranges were dropped onto a rotating steel drum, and the difference in rebound distance was used to separate soft and firm fruits. A method of clod separation using a similar technique of bouncing the objects on a revolving roller was developed by Feller *et al.*[14] for use with onions. The same method was also used for separating clods from potatoes in packing houses.[15]

3. Vibrational characteristics

The vibrational characteristics of fruits and vegetables are governed by their elastic modulus (firmness), mass, and geometry. Therefore, it is possible to evaluate firmness of fruits and vegetables based on their vibrational characteristics.

3.1. *Low frequency vibration*

Hamann and his co-workers[16,17] have found that small fruits such as blueberries and Muscadine grapes can be sorted on the basis of firmness by means of low frequency vibration. In this method the fruit is located in an L-shaped trough, one side of which vibrates at a specific frequency (about 200 Hz) and amplitude (about 0·3 mm). Fruits in a given firmness range will react by bouncing away from the vibrating surface and out of the trough into a collector. Bower and Rohrbach[18] have further studied this vibration method and constructed and tested a four-channel blueberry sorter.

3.2. *Sonic vibration*

The sonic vibration characteristics of fruits were studied by several researchers during the late 1960s and early 1970s. An extensive study of vibration characteristics of apples was conducted by Abbott *et al.*[19] They found that apples subjected to vibrational excitation display a series of resonant frequencies and that the second resonant frequency is associated with flexural vibrations and is strongly influenced by fruit size and firmness. They showed that fruit firmness is highly correlated with a stiffness coefficient, f^2m, where f and m are the second resonant frequency and mass of the fruit, respectively. Further studies were made by Finney,[20–22] who developed non-destructive techniques for evaluating firmness of intact apples and peaches. Finney and Abbott[23] presented a comprehensive review of techniques for measuring mechanical resonance, vibration transmissibility, pulse propagation velocity, and the resilience characteristics of solid food commodities.

3.3. *Acoustic response*

Many people have claimed that the maturity and other qualities of certain fruits, such as apples, melons, and pineapples, can be determined by listening to the sound produced by striking them. Several researchers have tried to verify such claims by studying the acoustic responses of fruits. Yamamoto *et al.*[24,25] developed a non-destructive technique for measuring textural quality of apples and watermelons based on the acoustic response of the fruit. They obtained the natural frequencies of the intact fruit by first recording the sound which is produced by hitting the fruit with a wooden ball pendulum and then performing Fourier transformation on the sound signal. They found that the natural frequencies of both apples and watermelons decreased with storage time. They also showed that the natural frequencies and firmness indices, expressed as functions of the natural frequency, mass, and density of the fruit, are significantly correlated with fruit firmness and sensory measurements. Salveit *et al.*[26] tried to use acoustic methods to determine the maturity of green tomatoes, but they did not obtain conclusive results.

3.4. *Ultrasonic methods*

Ultrasonic techniques have been used quite successfully for evaluating subcutaneous fat, total fat, lean, and other internal properties of live animals.[27–29] However, researchers have not been so successful in using ultrasonic measurements to evaluate internal quality of fruits and vegetables. Sarkar and Wolfe[30] conducted an investigation to assess the potential of ultrasonic techniques for quality evaluation of fresh and processed foods. They found that ultrasonic transmission could be used to evaluate the stability of reconstituted orange juice, reflectance measurements could be used to characterize orange skin texture, and a back-scatter technique could be used to detect cracks in tomatoes. However, they also found that the attenuation coefficient measurements of potato, cantaloupe, and apple tissues showed extremely high values within the frequency range of 0·5–1·0 MHz.

Similar results were found by Upchurch *et al.*[31] who tried unsuccessfully to use 1 MHz ultrasound to distinguish between damaged and undamaged apple tissue. They concluded that, because of the porous nature of fruit tissues, high frequency ultrasound cannot penetrate deeply into the fruit. For this reason it was difficult to use high frequency ultrasound to evaluate internal quality of fruits and vegetables. A similar problem was found by Gunasekaran and Paulsen,[32] who reported that ultrasonic methods were not suitable for detecting stress cracks in corn kernels because intercellular airspaces in the kernels blocked the ultrasonic wave transmission. However, Hoki and Tomita[33] reported that they successfully propagated lower frequency ultrasonic waves of 200 kHz through soybeans. They found good correlation between propagation velocity and moisture content in the beans. Mizrach *et al.*[34] also reported some success in using low frequency (50 kHz) ultrasonic excitation to determine some basic acoustic properties (wave propagation velocity, attenuation coefficient, and reflection loss) of certain fruits and vegetables.

4. Optical properties

One of the most practical and successful techniques for non-destructive quality evaluation and sorting of agricultural products is the electro-optical technique, based on the optical properties of the product.

When a light beam falls on an agricultural product, such as a fruit, only about 4% of the incident radiation is reflected off the surface as regular reflectance. The remaining radiation transmits through the surface, encounters small interfaces in the cellular structure, and scatters in all directions. A large portion of the radiation will be scattered back to the surface and leave the fruit in the vicinity of the point of incidence. Birth[35] suggested the term "body reflectance" for this type of reflection. The remaining scattered light diffuses deeper into the fruit and may eventually reach the fruit surface some distance away from the point of incidence. As the light travels through the fruit, a certain amount is absorbed by various constituents of the fruit. The absorption varies with the constituents, and the wavelength and path length of the light. The absorbed energy is transformed into other forms of energy. With some materials part of the absorbed radiation may be transformed into other forms of radiation, such as fluorescence and delayed-light emission. Thus, the radiation that leaves the surface of the fruit may consist of one or more of the following components: regular reflectance, body reflectance, transmittance, and emissions (fluorescence, phosphorescence, and delayed-light emission). The characteristics of the radiation that leaves the surface of the product depend on the properties of the product and the incident radiation. Thus, determining such optical characteristics of an agricultural product can provide information related to quality factors of the product.

4.1. *Quality index*

An important factor in evaluating the quality of food products by optical methods is the selection of quality indices (quantitative values formulated from one or more optical readings). A good quality index should have the following characteristics.

1. It should correlate well with the quality factor being evaluated.
2. It should not be easily affected by other physical parameters of the product.
3. It should vary little with apparatus variables, such as light-source intensity, light-detector sensitivity, and variation of the system response.

The general procedure is to study the optical characteristics of the product at various wavelength regions and select a set of wavelengths at which the optical readings appear to correlate with the quality factor. Quality indices are then formulated from optical measurements at one or more selected wavelengths. Birth[36] and Powers *et al.*[37] showed that a quality index which is expressed as a ratio of two optical measurements taken within a short time interval greatly minimizes the effect of instrument variables. Frequently used as a quality index in transmittance measurements is the optical-density difference (the difference in optical densities measured at two different wavelengths). Birth[38] suggested that measurements expressed in optical-density difference can be used to cancel the effects of sample size differences and sensitivity variation of the instrument. Birth[36] indicated that results are generally improved if the two wavelengths are close together. The difference of two optical readings at two close wavelengths is essentially the same as the slope of the spectral curve at either wavelength.

In many applications, optical characteristics can be analysed by visually studying the spectral curves and formulating the quality index from those wavelengths that seem to change with the quality factor. In recent years, however, with low-cost high-capacity microcomputers readily available, researchers have increasingly used computers in such analyses. A number of researchers have pioneered the use of spectrophotometer-computer interfaced systems to collect and analyse optical data.[39–41] With such a system, a researcher can study the optical measurements from a large number of samples and analyse the spectral data in more detail. More information related to quality factors of the product can thus be extracted, leading to more precise quality indices.

In the past three decades, researchers have studied the optical properties of various agricultural products and have established correlations between optical characteristics and other quality-related properties of the products. Optical reflectance has been used to evaluate certain characteristics near the surface of the product. Possible applications include maturity evaluation of fruit;[42–44] colour-sorting, as in sorting green and red tomatoes on a harvester or separating lemons into different colour groups;[37] detection of surface defects and contamination, such as defects on dried prunes,[45] mechanical injury, rots, moulds, scars, mite injury, and scabs on oranges[46] and tomatoes,[47,48] and bruise on apples;[49] separation of foreign materials, such as stones and dirt clods, from potatoes, onions, garlic, or tomatoes; detection of chicken broiler bruises; etc. Transmittance and absorption characteristics have been used to evaluate the internal quality of food products. Examples of applications include detection of blood spots in eggs,[50] water core in apples,[51] evaluation of fruit maturity,[52] internal colour of tomatoes, maturity of tomatoes,[53,54] dry matter in onions,[55] and many others. Fluorescence and delayed-light emission can be used to evaluate the maturity of fruits.[56–58] Tables which summarize these and other findings and include optical measurements of many agricultural products as related to various quality factors are given by Chen[59] and Gunasekaran *et al.*[60]

Several types of commercial sorting machines using diffuse reflection techniques are available for use on the harvester in the field or in the food processing plant. Most tomato harvesters in the USA are equipped with two colour sorters, each of which can remove green tomatoes and dirt clods from red tomatoes at a rate of up to 35 t/h. Similar sorters for sorting stones and dirt clods from harvested potatoes, onions, and garlic are also commercially available. Computer-controlled colour sorters are used in packing plants for sorting citrus, tomatoes, apples, and other fruits. It is estimated that over 95% of small commodities, such as beans, peanuts, coffee, peas, and rice, are now sorted by automatic sorters, which can sort up to 200 kg/h per channel.

4.2. *Near-infrared analysis*

Norris and his co-workers started to use near-infrared (NIR) radiation to detect the difference in moisture content in grain in the 1960s.[61,62] They subsequently studied NIR reflectance, and transmittance characteristics of many agricultural products and have found that radiation in the near-infrared region of the spectrum can provide information related to many quality factors of agricultural products. A very important contribution made by Norris and his co-workers was the development of data treatment techniques which make it possible to extract information from spectrophotometric data (curves). They found that diffuse reflectance, R, and diffuse transmittance, T, do not vary linearly with the concentration of an absorbing component in the material. Therefore, if a linear correlation between NIR measurements and the concentration of an absorber is desired, certain mathematical treatments of the reflectance or transmittance data are required.

Norris[63] summarized: "Diffuse reflectance, and transmittance spectra of agricultural products contain information about the chemical composition of the product because each of the components has specific absorption properties. The diffuse spectrum of a sample contains a summation of all of the overlapping absorption bands for each of the components within the sample, plus the contribution from all the scattering interfaces. Chemical composition can be predicted from high-precision, low-noise, diffuse reflectance, and transmittance spectra by a number of data treatments. Conversion of data to $\log(1/R)$ or $\log(1/T)$ gives adequate linearity between concentration of constituent and the measured optical parameter. Much of the overlapping of absorption bands can be resolved by computing the derivative from the spectral curves, and the use of a derivative at one wavelength divided by the derivative at another wavelength can cancel out path-length or light-scattering effects. Combining the derivative treatment with a single-term, linear-regression program to select the wavelengths provides for optimum calibration coefficients to predict the chemical composition". He gave several examples using derivative data treatments to predict the fat, moisture, and protein contents of meat from transmittance data; the oil and moisture content of individual intact sunflower and soybean seeds from transmittance data; and the composition of ground samples of wheat from reflectance data.

Until recently, analyses of NIR spectra were made in the wavelength domain. McClure and co-workers[64,65] have shown that Fourier analysis of NIR spectra can be used with several advantages. They found that an NIR spectrum can be transformed into a Fourier series, and the analysis can be made solely on the Fourier coefficients (Fourier domain). They have shown that only the first 50 Fourier coefficients are needed to represent essentially all of the information in many NIR spectra (each of which often contains more than 1000 data points), and only the first 11 coefficients are needed to estimate the contents of certain chemical constituents in the materials.

The research in NIR techniques has led to the development of various commercial NIR analysers for multiple constituent analysis of grains, oil seeds, meats, dairy products, feed, forages, etc. A very comprehensive book on basic fundamentals of near-infrared technology and NIR applications in the agricultural and food industries was compiled by Williams and Norris.[66]

5. Electrical properties

The study of electrical properties of agricultural products has interested many researchers in the past two decades. Numerous studies have been made to determine electrical and dielectric properties of a large variety of agricultural materials ranging from grains and seeds[67,68] to fruits and vegetables.[69,70] A comprehensive review of the electrical properties of agricultural products was published by Nelson.[71] The electrical properties of many agricultural products, especially hygroscopic materials, are highly dependent on moisture content. This relationship between moisture content and electrical properties was used as a basis for developing commercial instruments for measuring moisture content in grains and seeds. Two commonly used electrical moisture meters for grains and seeds are the conductance-type meters, which measure the conductivity of the product, and the capacitance-type meters, which measure the dielectric constant.

Zeleny[72] described the general principles and discussed the advantages and disadvantages of these two types of moisture meters. Conductance-type moisture meters are relatively easy to operate and to keep in proper adjustment. However, their accuracy can easily be affected by uneven moisture distribution within or among the kernels of the grain and is highly dependent upon the surface moisture of the kernels. Capacitance-type moisture meters are not so sensitive to uneven moisture distribution, but the accuracy and repeatability of results are sensitive to variations in the packing of seeds within the test cell. Matthews[73] discussed various factors that influence the design of capacitance-type moisture meters and described the design of a prototype moisture meter with improved features.

The sensitivity of electrical measurements to moisture content tends to mask changes in electrical properties associated with other variables. Zachariah[70] reported that a number of researchers have investigated the electrical properties of fruits and vegetables, and, although the results indicated some relationships between electrical properties and certain quality factors of the products, the results were not conclusive enough to permit development of a practical method for quality sorting of fruits and vegetables.

6. Nuclear magnetic resonance

Nuclear magnetic resonance (NMR) is a technique which detects the concentration of hydrogen nuclei (protons) and is sensitive to variations in the concentration and the binding state of water and oil in the material. Therefore, the NMR method can be used for evaluation of the moisture and oil content of grains and seeds.[74–78] Brusewitz and Stone[74] found that pulsed NMR techniques are more sensitive to moisture in wheat than are currently used dielectric techniques. The FID (free induction decay) ratio was linearly correlated with wheat moisture over the 8–15% moisture content range with a 0·98 coefficient of determination. Results of recent studies showed good potentials for using NMR techniques to evaluate sugar contents in apples and bananas[79] and oil contents in avocados.[80]

Although NMR imaging (MRI) has been used commercially in the medical field to detect tumors and other abnormalities in humans, its potential for detecting defects and other quality factors in fruits and vegetables has not been fully explored. Hinshaw *et al.*[81] have shown that MRI can produce high resolution images of biological objects. Wang *et al.*[82] used MRI methods to obtain images of watercore and its distribution in Red Delicious apples. Chen *et al.*[83] used MRI to evaluate various quality factors of fruits and vegetables. They found that MRI can provide high resolution images of internal structures of intact fruits and vegetables and can be used for non-destructive evaluation of various internal quality factors, such as bruises, dry regions, worm damage, internal breakdown, stage of maturity, and presence of voids, seeds, and pits. They also found that variation of experimental parameters, such as echo delay, resolution, and thickness of the scanning slice, can have profound effects on image enhancement of specific features of the specimen. Rollwitz *et al.*[84] suggest different types of portable NMR sensors for agricultural applications. Future development of low-cost NMR sensors would open a broad new range of promising applications in non-destructive quality evaluation of agricultural products.

7. X-rays and gamma rays

Short wave radiations such as X-rays and gamma rays can penetrate through most agricultural products. The level of transmission of these rays depends mainly on the mass density and mass absorption coefficient of the material. Thus, X-rays and gamma rays are suitable for non-destructive evaluation of quality factors which are associated with mass density variation. Both X-rays and gamma rays have been used for evaluating maturity of head lettuce which becomes denser as it matures. Lenker and Adrian[85] have developed a lettuce harvester which uses X-rays for selecting mature lettuce heads. Garrett and Talley[86] have also developed a lettuce maturity evaluating unit for use with a mechanical harvester, but the maturity selection of lettuce heads was based on gamma ray transmission. Researchers have found that X-ray techniques can be used to detect bruises in apples,[87] hollow heart in potatoes,[88,89] split pit in peaches,[90] and granulation in oranges.[91] Johnson described an electromechanical grader, developed by Sunkist Growers Inc., which used a low-level X-ray scanner to detect frost injury, granulation, and presence of *Alternaria* in oranges, based on the detection of variations in density within the fruit. X-rays have also been used to sort stones and clods from mechanically harvested potatoes. Palmer *et al.*[92] have developed an X-ray separator and demonstrated the feasibility of using such a separator on a commercial potato harvester to separate stones and dirt clods from harvested potatoes.

8. Machine vision

Interest is increasing in the development of machine vision systems to replace human visual inspection. One of the major requirements in developing machine vision systems for sorting fruits and vegetables is the ability to analyse an image accurately and quickly. Although various methods (use of a solid-state TV camera, line-scan camera, X-ray scanning, ultrasonic scanning, NMR imaging, etc.) can be used to obtain images of fruits and vegetables which show either external or internal features of certain quality factors, such as colour, shape, disease, injury, and defects, it has been difficult in the past to process such images to extract the desired feature information at an acceptable speed. Recently, the declining cost and increasing speeds and capabilities of specialized computer hardware for image processing have made computer vision systems more attractive for use in automatic inspection and sorting of agricultural and food products. Many researchers have devoted considerable effort towards the development of machine vision systems for different aspects of quality evaluation and sorting of agricultural products. As a result, new algorithms and hardware architectures have been developed for high-speed extraction of features which are related to specific quality factors of fruits and vegetables. Rehkugler and Throop[93,94] have developed a system for sorting bruised apples. Thomason[95] and Godinez[96] described a commercially available machine-vision system that can differentiate between irregular and erratic image features and predictable, normal image features. Some of the applications related to food products include detection of blemishes, grading of dates based on the amount of wrinkle, and removal of trash from vegetables.

Marchant *et al.*[97,98] developed a computer vision system for sorting potatoes into size and shape categories. The system which uses a multiprocessor architecture and a hardware data reduction unit can sort at a speed of up to 40 potatoes per second. Delwiche and his co-workers have developed a line-scan imaging system for detecting defects on dried prunes[99] and a colour vision system for colour grading of fresh market peaches.[100] Throop *et al.*[101] used the combination of light transmission and machine vision to detect watercore in apples. Bowers *et al.*[90] combined X-ray imaging and computer-vision image analysis to detect split pits in intact peaches. Berlow *et al.*[102] combined ultrasonic scanning and image processing to evaluate fat thickness and marbling characteristics of live beef cattle. Other applications include size grading of oyster meats,[103] detection of stress cracks in corn kernels,[32] determination of freeze-damage in citrus,[104] determination of orientation and other features of tomatoes,[105] and detection of cracks in eggs.[106]

9. Other sources of information

The above are highlights of only a few selected applications of non-destructive techniques for quality evaluation and sorting of agricultural products. Numerous other applications are not covered in this article. Readers who are interested in other applications are referred to works by Finney[107,108] Finney and Abbott,[23] Chen,[59] Mohsenin,[109], Gunasekaran *et al.*,[60] Dull,[110] Zaltzman *et al.*,[1] Nelson,[71] Williams and Norris,[66] and Gaffney.[111]

10. Conclusions

Several methods for non-destructive quality evaluation of agricultural products have been reviewed. Some methods are at a more advanced stage of development than others. Because each method is based on measurement of a given physical property, the effectiveness of the method depends on the correlation between the measured physical property and the quality factor of interest. Although researchers have developed relationships between physical properties and quality factors for a number of agricultural products, the inherent natural variability in structure, composition, and other variables within the same batch of agricultural products often makes it difficult to find good correlations between physical properties and quality factors. However, through use of computers and data processing techniques, researchers have been able to minimize the effects of extraneous factors and improve the correlations between some measured properties and quality factors of interest.

Earlier methods, such as those based on density, firmness, impact-rebound, and low frequency vibration, are more rudimentary and generally do not require high-speed electronic technologies. Their sorting speeds are not so high, and the accuracy is highly dependent on how well the measured parameters correlate with the quality factors. Methods based on electrical properties have been successfully used for measuring moisture contents for many years, but, in some applications, such methods have been gradually replaced by near infrared (NIR) techniques. The most successful and most widely utilized methods are the optical methods which incorporate high-speed optical sensing and data processing techniques to facilitate high-speed quality evaluation and sorting of many agricultural products with a high degree of accuracy.

The sophistication of non-destructive methods has evolved rapidly with modern technologies. The availability of high-speed data acquisition and processing technology has renewed researchers' interests in the development of impact and sonic response techniques. Some of these techniques will soon be available for commercial applications. The use of various modern image acquisition techniques, such as solid-state TV camera, line-scan camera, X-ray scanning, ultrasonic scanning, and NMR imaging, has enabled researchers to examine various quality factors of agricultural products in greater details. The combination of new imaging acquisition and high-speed image processing techniques has provided new tools for researchers to develop many new and improved techniques for non-destructive quality evaluation of agricultural products.

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