NONDESTRUCTIVE METHODS OF EVALUATING QUALITY OF FRESH FRUITS AND VEGETABLES

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Abstract

Current and new technologies are being utilized to develop better nondestructive methods for measuring fresh fruit and vegetable quality. These technologies include surface reflectance, diffuse reflectance, interactance (body transmittance), transmittance, fluorescence, delayed light emission, and imaging. These methods can be used to determine maturity, firmness, color, chemical composition, stress injury particularly due to chilling temperature, and/or defects. Effectiveness of the methods differs with technology, quality attribute, and commodity.

1. Introduction

In marketing fresh fruits and vegetables, quality and price are the determining factors in the sale of the product, and quality is the determining factor in acceptance when the commodity is consumed. However, quality grade is questioned many times between seller and buyer or even among sellers or buyers for a given item because quality is determined subjectively. Use of objective means to identify quality grade would minimize differences in opinions. Unfortunately, most current objective methods are destructive and the product is sacrificed with the analysis. To minimize these problems and to ensure described quality, research efforts are continually in progress to develop nondestructive methods of measuring quality.

Various methods using different technologies are being evaluated for measuring quality nondestructively. These technologies include surface reflectance, diffuse reflectance, transmittance, interactance (body transmittance), fluorescence, and delayed emission from illumination, imaging, X-ray, and measurements of acoustical, ultrasonic, vibrational, and deformation properties. This paper discusses methods that involve measurement of responses from illumination and use of imaging technology.

2. Technologies and Quality Measurements

With the optical methods, the spectral response is due to changes in a specific chemical component, and the quality is predicted from the correlation that exists between the chemical component and the quality attribute. Therefore, accuracy in assessment of maturity, color, or defects depends on the degree of correlation between the optical readings and the quality attribute. Quantification of taste, flavor, and aroma depends on the extended correlations between these attributes and maturity and between maturity and chemical components.

3. Surface reflectance

As the name implies, light reflected from an illuminated surface of the commodity is measured in this system. This technique is particularly effective with fruits that have uniform external color so that the quality condition of the fruit can be predicted from reflectance readings. Currently, this technology is used in grading lines of packing houses to sort tomatoes, oranges, lemons and apples according to defined color categories.

4. Diffuse reflectance

In diffuse reflectance, the light reflected from below the skin of an illuminated commodity or a few mm below the surface of an illuminated ground sample is quantified for the measurement. This method is applicable to samples where tissue condition or color below the skin or sample surface is better related to the quality attribute than the surface color. Diffuse reflectance measurements can be used to assess defects, color, and chemical composition.

4.1 Defects

Porteous et al. (1981) have described diseases and defects in potato tubers detected by measuring the diffuse spectral reflectance in the visible to near-infrared wavelength range. The only nonvisible disease detectable by this method was blight. Other diseases such as soft rot and scab can be quantified by this method if the diseases are visible. Effectiveness in quantifying diseases or defects is dependent on cleanliness and uniformity of the potato color.

4.2 Color

Color of lettuce (Brach et al., 1982) and oranges (Chuma et al., 1980) was monitored by diffuse reflectance to predict maturity. In lettuce, shift in absorption from the 640-660 nm to 700-750 nm range was useful in predicting maturity, whereas with orange, diffuse reflectance at 680 nm was the optimum wavelength for use in the automatic grading line of a packing house. With both commodities, the wavelength band for measurement was near that of chlorophyll absorption, so maturity was based on the degree of green coloration.

4.3 Composition

Near infrared diffuse reflectance spectra can be used to predict starch, protein, oil, and moisture contents of grains and oilseeds (Norris, 1983). Readings from the second derivative of the spectra are used to derive the multiple regression equations for predicting the chemical content. Particle size and temperature of the ground sample need to be standardized for effective analysis.

Application of this technology for measuring composition of fresh produce has not been satisfactory because of their high moisture content. In grains and oilseeds, the moisture content is below 15%, whereas it is above 85% in fresh fruits and vegetables. Concomitantly, the percentage content of the chemical components is much lower in produce than in oilseeds and cereal grains. With the huge differences between moisture and chemical content, any changes in the absorption spectra by the chemical component is masked by the absorption spectra of water.

5. Transmittance

Transmittance data on scattering samples are expressed in optical density (OD) + $\log_{10}(E_o/E)$ where E_o is the incident energy and E is the transmitted energy. The OD includes the energy loss from reflectance and scatter as well as from absorption. Most samples contain more than one compound that absorbs radiation in the spectral region under test. To minimize the effects from all but the desired compound, the difference in OD (Δ OD) at two wavelengths is used to relate spectrophotometric measurements to quality attributes.

5.1 Defects

Defects can be detected by transmittance if the color of the defect is darker than that of the surrounding normal tissue. Defects with darker than normal color include hollow heart in potato tubers and core breakdown in pears. Hollow heart of potato tubers can be determined by measuring ΔOD (800-710 nm) (Birth, 1960). The severity cannot be recognized appropriately if the potato flesh color shows yellowing. Core breakdown of pears can be detected by taking ΔOD readings at 690-740 nm (Wang, 1979). The ΔOD readings decrease with softening of pear, but readings will increase with development of core breakdown. This technique is particularly useful for detecting core breakdown that is not visible externally.

In some defects, water moves into the intercellular area. This intercellular water decreases light scatter and causes transmittance to increase. In apples with water core, the tissue around the vascular bundles near the core becomes water-soaked in appearance and the severity can be estimated by ΔOD (810--760 nm). Detection of water core in apple nondestructively allows separation of severely affected apples during grading prior to storage and elimination of costs of handling and storage of water core apples that would not be acceptable after storage. A hand held model is now available commercially for random sampling of apples for water core.

5.2 Maturity

Maturity is predicted on the basis of associated chemical changes which are measured by transmittance readings. Maturity of pears, as defined by the firmness condition, can be estimated by Δ OD (690-740 nm) readings (Wang, 1979). The readings can be used to predict firmnes of 'Bartlett' pears softening from 60 to 20 n. Attempts ha been made to predict ripeness of cherries by measuring absorbance at 600-730 nm, but the predictability was not satisfactory (Csabaffy, 1984). Since seeds are very dense and the surface color of seeds can be highly variable, see may interfere with absorbance readings.

Maturity of tomatoes can be predicted on the basis of chlorophyll and lycopene content. Δ OD (710-780 nm) readings were used to predict chlorophyll content ranging from 1-12 g/g fresh weight, and Δ OD (570-780 nm) readings were used to predict lycopene content ranging from 0-40 g/g fresh weight of 'Walter' tomatoes (Watada et al., 1976). These readings have been useful in predicting the time when a mature green tomato will become table ripe. Mature green tomatoes as described here are those fruit that do not show any external ripening color. Use of this technique is more effective with tomatoes that have uniform green color than those having dark green shoulders. On the basis of pigment content, maturity of apples (Watada et al., 1985) and peaches (Watada and Norris, 1978) can be determined.

6. Interactance/Body Transmittance

The term used to describe this method was initially 'body reflectance' and has been changed to 'interactance' by some scientists and 'body transmittance' by other scientists. Development of this technology was due in part to the limitation or restriction of the transmittance method. In the transmittance method, light had to be transmitted through the commodity and a very sensitive detector was required to measure small changes at 10^{-12} OD. This was not feasible with many commodities, so the technology was modified to obtain transmittance readings at an angle from the direction of illumination. The depth of transmittance for such measurement was only a few mm below the skin or surface of a sample, so the application of the technique is limited to commodities where the tissue condition near the skin or surface can be correlated with quality.

6.1 Maturity

Maturity of papaya was predicted by Birth et al. (1 984) on the basis of chlorophyll, carotenoid and soluble solids content that was determined from the interactance measurements. They examined the interactance in the 500-900 nm wavelength range and found that chlorophyll, cartoenoids, and soluble solids can be quantified from measurements at wavelengths of 588 and 620 nm, 520 and 643 nm, and 582 and 714 nm with the corresponding constants, respectively.

6.2 Composition

Dry matter content of onions can be determined effectively by interactance measurements at near infrared wavelengths (Birth et al., 1985). The second derivative of the spectra at wavelengths from 700-1000 nm was used to derive the multiple regression equation for predicting dry matter of onions ranging from 5-25%. The wavelengths selected for the analysis imply that the absorption band is associated with carbohydrates as the main dry matter in onions. Since soluble solids are mostly carbohydrates, this technology was examined to measure soluble solids in cantaloupe (Dull et al., 1988). Predictability was good for slices, but not as good for a whole, intact fruit, probably because of variation in the composition and structure of netting.

Amounts of water, protein, oil and carbohydrates in oilseeds and grains can be predicted from interactance measurements similarly to the diffuse reflectance method.

7. Fluorescence

Fluorescence by chlorophyll has been used to determine the effect of stress conditions on crop plants, where the degree of response was based on time required for fluorescence to decay 50%. Kamps et al. (1987) used this method successfully for objectively categorizing tomato genotypes according to susceptibility to chilling.

8. Delayed light emission

8.1 Maturity/Color

Chuma et al. (1982a, b, c, d, e) developed a method measuring response from decay of delayed light emission (DLE) after single illumination for sorting tomatoes, persimmons, and apricots according to color or maturity. For DLE measurements, optimum time periods of dark period prior to illumination, illumination period, and decay period of DLE had to be defined for each type of fruit. Optimum dark periods were 15, 20, and 5 minutes, optimum illumination periods were 2 seconds, 1 second, and 300 milliseconds and DLE decay periods were 2, 1.5, and 5 seconds for persimmons, apricots, and tomatoes, respectively. Maximum DLE response occurred at near 650 nm, which is near the absorption band of chlorophyll. With tomatoes, Chuma et al. (1982a) and Forbus et al. (1985) were able to effectively separate green tomatoes from those that were beginning to ripen.

8.2 Chilling injury

Chilling temperatures are deleterious to chlorophyll activities, so changes in activities can be detected by

DLE. Abbott and Massie (1985) found that repetitive measurements of DLE were more effective than measurements of decay from single illumination to detect stress caused by chilling temperatures. For DLE measurements, cucumbers were kept in dark for at least 30 min prior to measurements, then illuminated 7 msec, kept in dark 0.5 msec, DLE measured for 7 msec, and kept in dark 0.5 msec. This cycle, taking 15 msec, was then repeated for 15 sec. The DLE amplitude increased with time and the maximum amplitude was lower with cucumbers held at lower chilling temperatures. However, the slope of change within the first 1.5 sec was greater with increasing amount of chilling stress or injury, and the slope was used to quantify stress. This technique was used to demonstrate that cucumbers showed stress after 24-36 h at 2.5C, which was at least 48 h before any symptoms of injury became visible.

9. Imaging

Imaging is a new technology which requires powerful and expensive instrumentation for detecting surface defects or injuries of fruit or defects occurring internally. With advancement of technology accessibility to imaging equipment should increase rapidly. For surface defects, an algorithm of the gray level of pixels is used to determine the extent of defect or physical injury on the surface. Significant progress has been made in the imaging technique for separating peaches according to blush color (Miller and Delwiche et al., 1988), separating good and defective dried prunes (Delwiche et al. 1988), and recognizing bruises from scab, hail damage, bird pecks and insect stings on apples (Rehkugler and Throop, 1987).

The nuclear magnetic resonance (NMR) imaging method in radiology is used to detect fruit defects occurring internally. Cross-sectional images of defects are reconstructed on the basis of uneven distribution of mobile water and its NMR relaxation times, spin-lattice and spin-spin. S. Y. Wang et al. (1988) were able to clearly define morphology of an apple as well as areas affected by water core from NMR images. Their image data indicate that water core occurred primarily in the area ±20 mm from the center of the fruit of an affected apple, and the area most affected was between 5 and 10 mm from the center, toward the stem end. Core breakdown in 'Bartlett' pears was detected and its development monitored by this technique (Wang and Wang, 1988). Distinct degeneration of the tissue was shown to occur in the periphery of the core area of the pear after 3 months of storage at OC in air and 4 days of ripening at 20C. The collapse of the tissue worsened with time and the extension of disorder to the calyx end of the fruit was noted by the 6th day.

10. Conclusion

Technologies for assessing quality of fresh fruits and vegetables are continually improving. Effectiveness of the technology differs with method and commodity, as well as interpretation of data. The more advanced technologies are expensive and uses are currently limited. However, with the advancement of technology, as shown in the past, cost of these instruments will become reasonable and readily available for research and commercial use.

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