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LED-induced fluorescence spectroscopy technique for apple freshness and quality detection

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ABSTRACT

The LED-induced fluorescence spectroscopy technique is developed to detect apple freshness and quality. A compact and automatic system is set up for fast measurements of apple fluorescence spectra. The partial least square regression (PLSR) method is used to establish a predictive model between fluorescence signals and corresponding actual apple qualities. Apple freshness is related to physiological aging, and apple quality is expressed by firmness (F) and soluble solids content (SSC). As for freshness detection, an LED at 375 nm is demonstrated to be more effective than at 400 nm with a root mean square error of validation (RMSEV) of 4.73 d. Meanwhile, the prediction results of the firmness and SSC for two kinds of apples also show low RMSEV values of 6.88 N and 0.98%, respectively, indicating that the LED-induced fluorescence spectroscopy technique is an effective, convenient and promising method for scanning apples and perhaps other foods.

1. Introduction

Apples, which originated in Central Asia and Europe, are one of the most important traditional table fruits in the temperate zone (Harris et al., 2002; Péneau et al., 2006). At present, China is the largest cultivation country of apples (Dong and Guo, 2015), exporting about 995 thousand tons of apples to the rest of the world in 2013 (National Bureau of Statistic of People's Republic of China 2014). Consumer choice of apples is driven by the trade-off between price and quality (Harker et al., 2003). Sorting apples based on internal quality can enhance the industry's profitability and ensure consumer satisfaction (Mendoza et al., 2014). To provide high-quality apples for the market, the following parameters should be of concern. Firmness and soluble solids content (SSC) are crucial quality attributes that directly influence consumers on purchasing apples (Lammertyn et al., 1998). In addition, freshness is another decisive characteristic for consumer choices (Babicz-Zielinska and Zagorska, 1998). Consumption may increase if apples of satisfactory freshness and quality are provided for consumers (Péneau et al., 2007). However, there does not exist a standard definition for the degree of apple freshness. In this research, freshness is indicated by physiological ageing (Peirs et al., 2005).

The common method for apple flesh firmness analysis is the Magness-Taylor puncture test, while SSC is determined by analyzing juices extracted from apple fleshes with the refractometric method (Qing et al., 2008; Noh and Lu, 2007). Nevertheless, it is too destructive and time-consuming for online sorting applications. Fluorescence spectroscopy, which is a rapid, sensitive, and non-destructive analytical technique, can provide spectral signatures that can be used as fingerprints of investigated food products (SádeCká and TóThoVá, 2007). Laser-induced fluorescence spectroscopy was applied to a tea classification and quality assessment (Mei et al., 2012) and on strawberry fruits for quantitative analyses of phenolic compounds (Wulf et al., 2008). Some researchers used chlorophyll fluorescence as a potential predictor of superficial scald development during apple storage (DeEll et al., 1996) and as an estimation of anthocyanins as well as total flavonoids in apples (Hagen et al., 2006). However, to the best of our knowledge, the fluorescence spectroscopy technique has not ever been used to evaluate the firmness, SSC or freshness of apples. On the other hand, light-emitting-diode (LED) induced fluorescence spectroscopy, which is more compact and inexpensive compared to laser-based technique, has been demonstrated to be an effective technique for quantitative detections. It has also been

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used in real-time detection and quantification of dental calculus (Qin et al., 2007), and trace amount of organics in drinking water and water sources (Sharikova, 2009). However, little research has focused on fruit detection. In the present work, an LED-induced fluorescence system with different excitation wavelengths, that is effective, flexible and low-cost, has been developed to measure the freshness and quality of apples. LED-induced fluorescence spectroscopy shows great potential for fruit detection and our compact system could be useful for commercialization in the future.

2. Materials and methods

2.1. Apple samples

Two kinds of Fuji apples, which come from Shandong and Shanxi Province, China, were bought from the campus supermarket during the harvest season. After the apples were transported to the laboratory, they were kept in the incubator and stored at room temperature ($22 \pm 2\,^{\circ}C$). Before the experiment, the apples were taken out and washed with tap water to remove foreign materials on their surfaces and then wiped dry. Altogether 160 apples were tested for our research, 112 of which, i.e., 56 of each kind, were utilized for firmness and SSC detection, while the remaining 48 apples (24 of each kind) were used for freshness measurements over a long period (nearly a month).

2.2. System setup

The LED-induced fluorescence system setup is shown in Fig. 1. Apples were placed on an anodized aluminum plate, which could be rotated by a step motor. The apples were irradiated by LEDs in the measurements, the fluorescence spectra of which were obtained automatically at eight locations. LEDs at 375 nm and 400 nm with largest intensities about 20 mW and bandwidths of about 10–20 nm were installed on the compact sensor head, which is a truncated cone-shaped cavity made of polished aluminum. The LEDs could be turned on individually, the emission intensities of which were controlled by a data acquisition card (DAQ, National Instruments, USB 6008, USA) through a driving circuit. The incident angle of the excitation radiation was set at about 60° to minimize the reflected and scattered radiation (Le Moigne et al., 2008). Fluorescence generated from the apple samples were filtered by either 400 nm or 450 nm long-pass filters (OD 4High Performance Long-pass Filter, Edmund Optics Inc., Barrington, USA) to eliminate the direct reflective light at the corresponding excitation wavelengths. They were then collected by a multimode fiber with a core diameter of 1.0 mm and recorded by an optical spectrum analyzer (OSA, USB2000, Ocean Optics Inc., Dunedin, USA). The signals were finally transmitted into the computer by the DAQ and processed by Matlab software (The MathWorks Inc., Natick, USA). A Labview (National Instruments, USA) program was utilized to control both the DAQ and OSA to achieve automatic measurement.

2.3. Fluorescence and destructive measurement

The fluorescence measurements for each sample were performed at eight locations around the equator of the apples to ensure that different sections of the sample were illuminated. For each fluorescence spectrum, the data were averaged to represent one sample. For the freshness test, a total of 288 original fluorescence spectra were obtained at six distinct times (storage days: 1, 6, 11, 18, 24, 29). For the quality test, each kind of apple sample was measured 3 times to build an accurate estimation model, so a total of 336 original fluorescence spectra were obtained for subsequent analysis.

The destructive test was performed right after the apple quality detection. Apple flesh firmness expressed in N was measured with puncture testing equipment (HANDPI GY-3, China). Apple skins were removed in the measurement. A cylindrical probe with a diameter of 11 mm was inserted 10 mm deep into the apple tissue. After firmness measurements, the apple juices were immediately squeezed. SSC expressed in% was then determined by a refractometer (ATAGO, Japan).

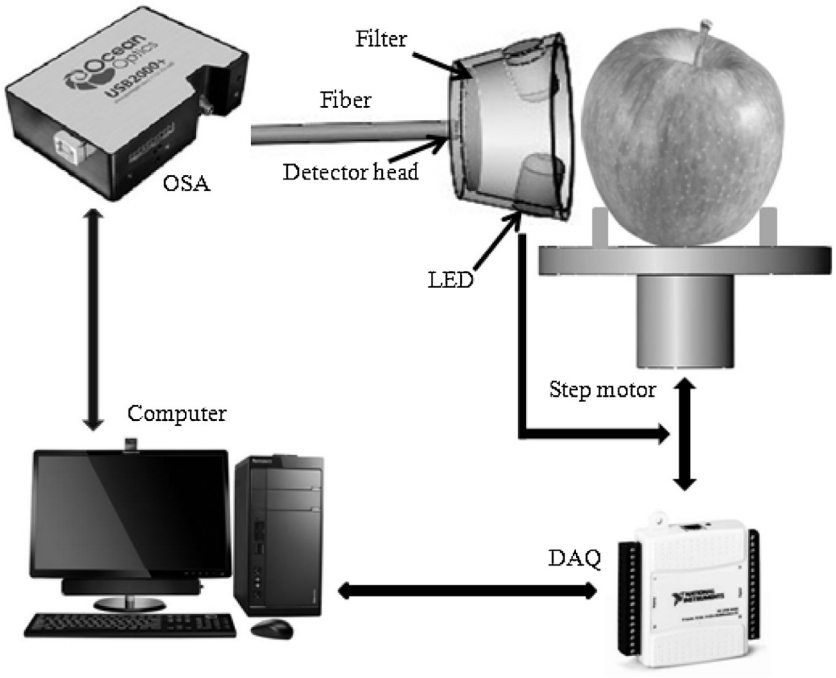

Fig. 1. Schematic diagram of LED-induced fluorescence spectroscopy system.