Postharvest Biology and Technology 90 (2014) 1–6

Contents lists available at ScienceDirect

Postharvest Biology and Technology

journal homepage: www.elsevier.com/locate/postharvbio

Using visible and near infrared diffuse transmittance technique to predict soluble solids content of watermelon in an on-line detection system

Dengfei Jie, Lijuan Xie, Xiuqin Rao, Yibin Ying*

College of Biosystems Engineering and Food Science, Zhejiang University, 866 Yuhangtang Road, 310058 Hangzhou, China

ARTICLE INFO

Article history:
Received 29 September 2013
Accepted 23 November 2013

Keywords:
Near infrared spectroscopy
Monte Carlo-uninformative variable elimination
Watermelon
On-line determination
Stepwise multiple linear regression

ABSTRACT

Sugar content is one of the most important factors determining the eating quality of watermelon fruit. In order to detect the fruit soluble solids content (SSC) on-line, this work develops a nondestructive on-line detection prototype system using visible and near-infrared (Vis/NIR) technology. For the acquisition of the diffuse transmittance spectrum of watermelon, the conveyor was set at a speed of 0.3 m/s and ten 150 W tungsten halogen lamps were used as the light source. The crucial model for SSC value prediction was optimized by chemometrics. Partial least squares regression (PLSR), stepwise multiple linear regressions (SMLR), Monte-Carlo uninformative variable elimination (MC-UVE) and genetic algorithms (GA) were applied to the spectra in the range of 687–920 nm. The data pre-processing methods were optimized to transmittance spectra with baseline offset correction (BOC), and the BOC-MC-UVE-SMLR calibration model was the best with a correlation coefficient (r_{pre}) of 0.70, root mean square error of prediction (RMSEP) of 0.33 °Brix for the prediction set. In on-line testing of 30 samples, the r_{pre} was 0.66 and RMSEP was 0.39 °Brix. The results showed that a nondestructive on-line SSC value determination prototype based on Vis/NIR technology was feasible.

1. Introduction

Watermelon (*Citrullus lanatus* (*Thunb.*)) is a widely produced fruit, and for consumer satisfaction, product value and repeat purchasing, fruit internal quality is important (Walsh, 2005). It is correlated with a number of variables, including sugar content, acid content, juiciness, texture, firmness, volatile contents, and other properties. High sugar content is one of the major characteristics used for assessing watermelon internal quality (Semmelmeyer, 2006).

The increasing demands of volume production and internal quality assurance in the fruit industry contribute to the development of advanced rapid, real-time, reliable and non-invasive technologies for fruit quality determination. Conventional laboratory analytical techniques are destructive, manual, time consuming, require use of hazardous chemicals and are labor intensive. Near-infrared (NIR) spectroscopy is nondestructive, rapid, simple, in real-time, with no use of toxic reagents and with relatively reduced operational costs, which are appropriate for on-line application. However, most of the former studies on watermelon detection using NIR spectroscopy have been focused on the watermelon with static detection. There is little systematic theory or detailed research reports except for some commercial applications of on-line detection systems for watermelon based on the NIR technique (Sun et al., 2010). Some commercial companies (FANTEC Co., Ltd., Sumitomo Metal Mining Co., Ltd., and Shizuoka Shibuya Seiki Co., Ltd.) have successfully developed watermelon sorting machines for ripeness and cavity determination based on NIR technology and acoustic properties. SACMI (SACMI Machinery Equipment Co., Ltd.) developed an NIR BOX for melons and small watermelons of up to 2 kg.

With difficulties due to the optical thickness of watermelon rind, differences in sweetness between the center and external parts of the flesh (Kato, 1997), and high water content (typically 90%, w/w) (Liang, 2001), it is necessary to design a special system based on NIR spectroscopy for internal information acquisition (increased light intensity, increased integration time or increased spectrometer aperture/detector size) (Walsh et al., 2000). The NIR diffuse transmission method has been successfully used to predict sugar content in watermelon, using a combination of high illumination (16 lamps surrounding the sample with the detector contacting the fruit) and a 10 s measuring time, and the standard deviation (SD) of soluble solids content (SSC) was 0.61 °Brix (Aoki et al., 1996), as was the case in our earlier work (Jie et al., 2013). In this method, radiation is detected after penetrating deeply through the body of the fruit, thus obtaining more internal information from all parts of the

---

* Corresponding author. Tel.: +86 571 88982885; fax: +86 571 88982885.
E-mail address: yingyb@zju.edu.cn (Y. Ying).

0925-5214/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.postharvbio.2013.11.009

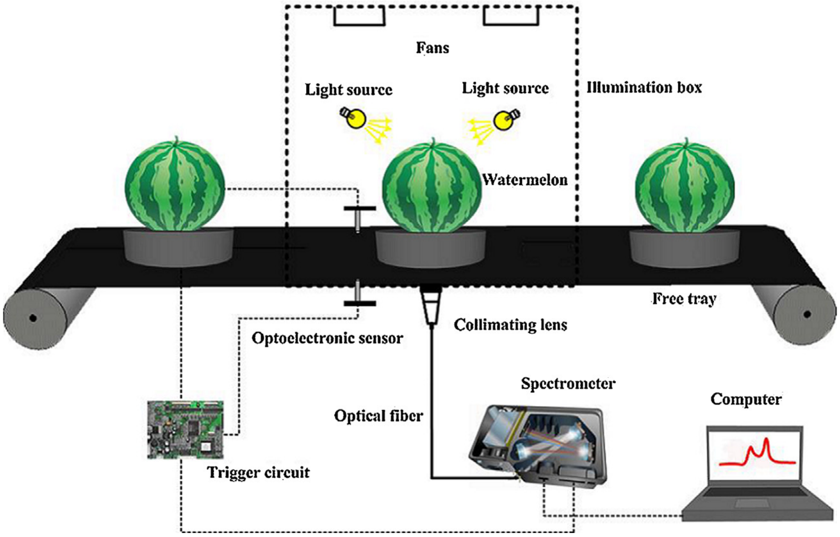

Fig. 1. Schematic of spectra on-line measurement prototype system.

fruit and making whole fruit sugar content assessment possible. SSC was chosen as one of the most important internal quality factors for evaluation. The commercial large-scale on-line fruit internal quality detection instruments using NIR spectroscopy have shown that visible and near-infrared spectroscopy (Vis/NIRS) is a promising technique to predict the SSC value of intact watermelons.

To approach the on-line detection SSC value of watermelons, we have developed a complete determination system include the hardware and software for SSC prediction. The main objectives of this work were to: (1) develop a prototype detection system that could be used for on-line detection in a nondestructive way based on the Vis/NIRS technique; (2) further test the usefulness of the system for on-line detection of large watermelon SSC values; (3) simplify the on-line predictive model.

2. Materials and methods

2.1. On-line detection system

The on-line measurement prototype system for watermelon sugar content detection (Fig. 1) used a motor driven conveyor for fruit movement. There was a hole in the center of the tray (the diameter is 300 mm) with diameter of 50 mm, and these were placed on the conveyor belt. The free tray was designed to block the light leaking through the contact surface between the samples and the tray, concentric grooves were made inside the tray and ring shape silicon pads were put on the tray to accommodate varying watermelon shape and size (Abebe, 2006). In order to eliminate interference from environmental background radiation as far as possible, an illumination box optical device was used for NIR diffuse transmittance measurement. In this box, light sources comprised ten 150 W commercial-grade tungsten halogen lamps powered by a full-stabilized DC power supply. An adjustable collimating lenses (diameter 50 mm) embedded optical fiber (Ocean Optics Inc., USA) connected to a commercial miniature fiber optic spectrometer (Ocean Optics Inc., USA) was used to diffuse transmitted light collection through the center hole of the free tray.

When spectral acquisitions were made, each sample was put on a tray and was fed onto the conveyor belt and moved into the illumination box at a speed of 0.3 m/s. The spectrometer was set to external trigger mode to collect spectral data. A pair of optoelectronic sensors (SIKO SENSOR Co., Ltd., Nanjing, China) acted as a switch of the spectrometer. The position of the trigger was decided by the relative location of the holes on the conveyor belt and in the tray. When the sample came to the given location in the illumination box, the optoelectronic sensor transmitted an electrical signal to the computer, and then the computer controlled the spectrometer to spectral collection automatically in the integration time. Reference and dark spectra were measured before sample spectral measurement. The reference was measured with each set of samples. Spectrometer parameters settings, and spectra collection and storage were carried out via software developed by ourselves.

2.2. Spectra acquisition

One hundred samples of Qilin (*Cucimus melo*) watermelon were harvested from a local farm in Hangzhou, Zhejiang Province, China. All fruit were cleaned and held at room temperature (25 °C) for 24 h before spectra acquisition. The characteristic parameters (equator diameter, length and rind thickness) were obtained using a vernier caliper (Shenhan measurements tools Co., Ltd., Shanghai, China). After seven samples with different defects were eliminated, 93 intact watermelons were employed for further analysis, with 62 samples randomly chosen as a calibration set and the other 31 as the prediction set (a ratio of 2:1).

Samples were manually loaded on the free tray. The measurement was expressed as percent transmission (%*T*). Integration time was optimized to record maximum counts without saturation, since previous work has shown that if the acquired count level was approximately 5% of detector saturation, it would result in a low signal to noise ratio (SNR) and poor calibration performance (Greensill, 2000). The integration time of the spectrometer was set to 200 ms. We acquired the spectra after the spectrometer and light source warmed up to a stable status.

2.3. SSC determination

After spectra acquisition, all watermelons were cut into halves from stem end to calyx end and edible portions were removed and cut into pieces for obtaining watermelon juice using a juicer (Liven SCI-TECH CO., Ltd., LL-A small cyclone juicer, Beijing, China), the juice was poured into a conical flask with filter paper (medium speed type, 30–50 μm, Shuangquan Brand, China), and clear juice was obtained. A digital refractometer (Atago Co., Ltd., PR-201α Brix-Meter, Tokyo, Japan) with a °Brix range of 0–60 and ±0.1 °Brix accuracy was used to determine SSC values (°Brix). The value of SSC