Time-of-flight near infrared spectroscopy for detecting sugar and acid contents in thick-peel fruit

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Introduction

The conventional optical method, using a tungsten-halogen lamp as light source, cannot detect inner information of thick-peel fruit such as grapefruit, because NIR radiation is absorbed and strongly scattered in the peel. We have proposed a hyphenated technique between time-of-flight (TOF), which uses short pulses of illumination, and NIR spectroscopy, that is named as TOF-NIRS.[1,2] This system combines the best features of the spectrophotometer and the laser beam. The behavior of transmitted radiation could be observed by a time-resolved state within a very short time domain.

We examined the applicability of TOF-NIRS for detecting sugar and acid contents in thick-peel fruit like grapefruit. We also paid attention to the cross-correlation function between input pulsed laser and the transmitted beam for signal processing.

Materials and methods

The samples used were commercial White grapefruit harvested at Florida, USA. Basic composition of the grapefruit samples is shown in Table 1.

The system mainly consists of an exciter laser (Wedge HB-532-SC,Bright Solutions, Cura Carpignano, Italy), a laser tunable unit (XA-JB, SEIKO Electric Co., Fukuoka, Japan), two avalanche photodiodes (C5658, HAMAMATSU Photonics Co., Japan), and a digital oscilloscope (TDS 3052B, Tektronix Japan Ltd., Tokyo, Japan). The wavelength of the laser output from dye-doped plastic was tuned from 740 nm to 860 nm (every 10 nm).[3] The equator area of each fruit was irradiated vertically with the pulsed laser beam, and the transmitted radiation was detected at its opposite face (Figure 1).

The laser output, as time-resolved profile, could not give constant peaks due to the exciting characteristics of Nd:YAG laser. For this reason, we paid attention to the cross-correlation function between the reference and transmitted beam. The cross-correlation is a measure of similarity

Table 1. Basic composition of grapefruit samples.

	Average	Standard deviation	Minimum	Maximum
Diameter (mm)	92	2.64	86	98
Brix (%)	9.71	0.51	8.50	11.30
Acid (%)	1.36	0.14	0.95	1.77

of two signals, commonly used to find features in an unknown signal by comparing it to a known one.[1] It is a function of the relative time between the signals, and has applications in pattern recognition. In the case of our measurements, the time-resolved profile for the reference beam was designated as $x(t)$ and the transmitted beam from the object as $y(t)$, respectively. The cross-correlation function $R_{xy}(\tau)$ is defined as follows this equation:

$$R_{xy}(\tau) = \lim_{T\to\infty} \int_0^T x(t)\, y(t+\tau)\, \mathrm{d}t$$

The cross-correlation function is a stable signal to cancel the variation of pulsed laser and was employed as the explanatory variable. Sugar and acid contents as the reference data were measured by traditional saccharimeter (ATAGO Co., Tokyo, Japan) and sodium hydroxide titration, respectively.

PLS analysis to predict the inner information of grapefruits was examined using 'The Unscrambler' software, (Camo, Oslo, Norway). Evaluation of the model was performed by full cross validation.

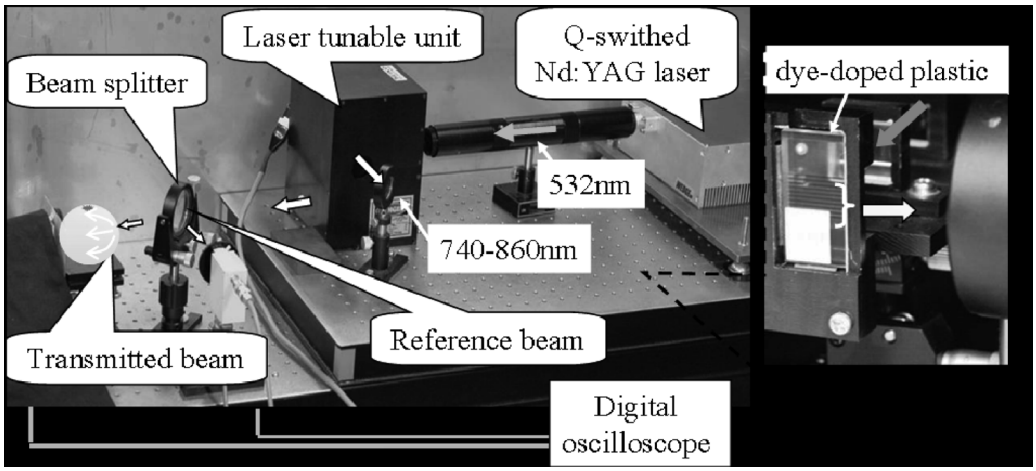

Figure 1. Schematic diagram of measuring system.

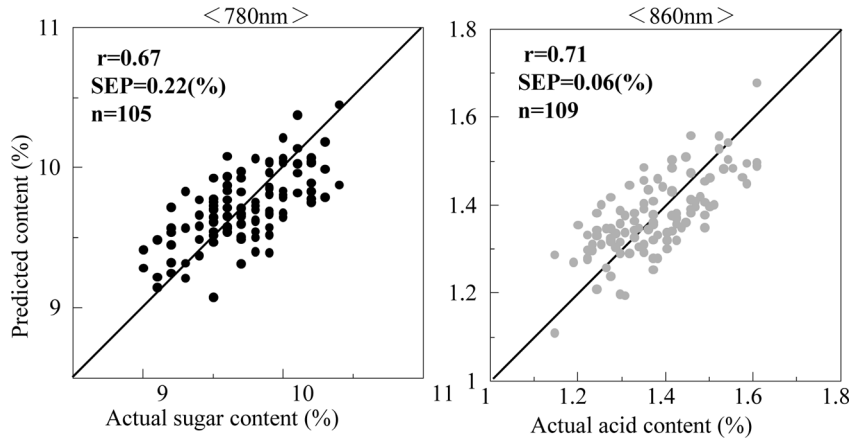

Figure 2. Relationship between measured and predicted sugar and acid concentrations in grapefruit.

Results and discussion

Figure 2 shows the relationships between measured and predicted sugar and acid contents, respectively.

In this research, the pulse laser of 780 nm gave the best result to predict sugar content and that of 860nm was the best wavelength for acid content prediction. It was possible to predict both sugar

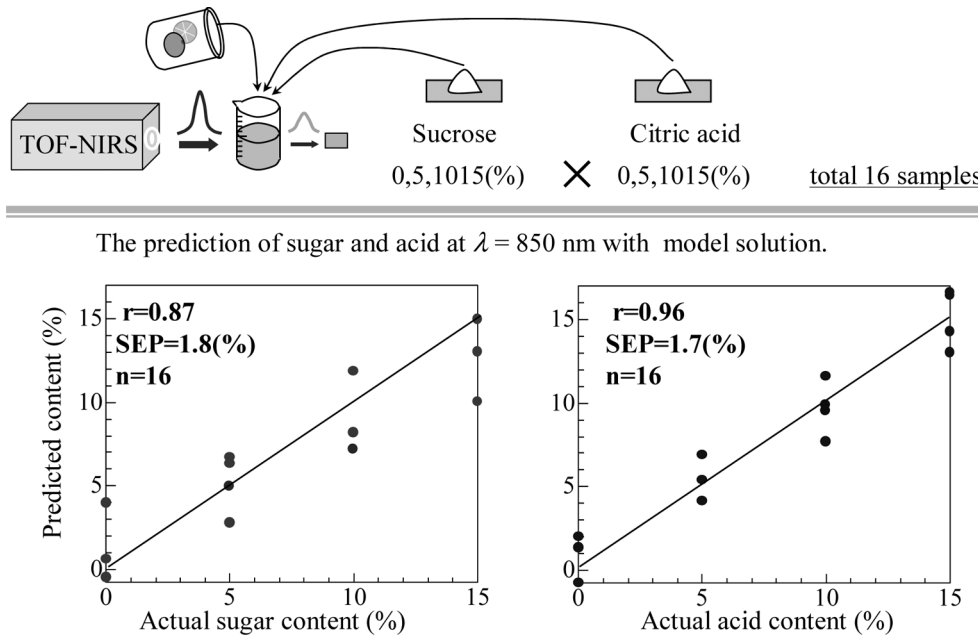

Figure 3. Relationship between measured and predicted sugar and acid concentration with the model solution.

and acid contents of grapefruit with high efficiency. In the same way, the solution was adjusted as shown in Figure 3, and measured with TOF-NIRS at 850 nm. For sugar prediction the R value was 0.87, and 0.96 for the acid prediction (see Figure 3).

It was possible to predict both sugar and acid contents in the model solution with high efficiency.

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